VOLUME II NUMBER 2

THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

EDITOR

C. A. CHANT
University of Toronto, Toronto

ASSOCIATE EDITORS

W. F. KING
Chief Astronomer
Ottawa

R. F. STUPART
Director of the Meteorological Service of Canada, Toronto

J. S. PLASKETT
Dominion Observatory
Ottawa

PUBLISHED BI-MONTHLY

MARCH-APRIL, 1908

PRINTED FOR THE SOCIETY
TORONTO: 198 COLLEGE ST.
FOREIGN AGENTS: WILLIAM WESLEY & SON,
28 ESSEX ST., STRAND, LONDON.

THE JOURNAL

OF THE

ROYAL ASTRONOMICAL SOCIETY

OF CANADA

PUBLISHED BI-MONTHLY

THE TRANSACTIONS OF THE SOCIETY APPEAR IN THE *Journal*.

VOL. II. MARCH-APRIL, 1908. No. 2

Earthquakes and the Interior of the Earth	*Otto Klotz*	51
The Orbits and "Velocity Curves" of Spectroscopic Binaries	*J. Miller Barr*	70
Lunar Tides on Lake Huron	*W. J. Loudon*	82
Determination of the 141st Meridian	*F. A. McDiarmid*	84
Treasurer's Report		96
Meetings of the Society at Toronto	*E. A. D.*	97
" " " " " Ottawa	*J. S. P.*	99
" " " " " Peterborough	*E. F.*	103
Notes from the Dominion Observatory		106
Astronomical Notes		111
Summary Report of Weather in Canada for February and March		112

Editorial communications should be addressed to C. A. Chant, University of Toronto, Toronto, Ont.

Business correspondence, remittances, etc., should be addressed to George Ridout, Treasurer of the Society, Nordheimer Building, Toronto.

$2.00 per annum. Single numbers, 35 cents.

Subscription to the *Journal* and the Society's Annual *Handbook* is included in membership fee.

University of Toronto

INSTRUCTION given in the University Faculties of Arts (degrees of B.A., M.A. and Ph.D.), Medicine (M.B. and M.D.), Applied Science (B.A.Sc., C.E., M.E., E.E.), and in the Colleges and Schools of Dentistry, Pharmacy, Agriculture, Music, Household Science and Veterinary Science.

Fully equipped Library and Science Laboratories, Gymnasium and Recreation grounds for Physical Culture.

Thorough course of preparation in all branches for professional or business career.

For calendar and all information apply to JAMES BREBNER, B.A., Registrar.

University College

UNIVERSITY COLLEGE is, since the Federation Act of 1887, the complement, in the system of higher education provided by the State, of the University of Toronto.

The State furnishes through University College, instruction in those departments of the Arts Course in which it does not furnish instruction through the University.

These departments are Greek, Latin, Ancient History, English, French, German, Oriental Languages and Ethics.

MALCOLM W. WALLACE, Ph.D., Registrar.

THE JOURNAL
OF THE
ROYAL ASTRONOMICAL SOCIETY
OF CANADA

VOL. II. MARCH-APRIL, 1908. No. 2

EARTHQUAKES AND THE INTERIOR OF THE EARTH*

BY OTTO KLOTZ

IN the ninth edition of the *Encyclopædia Britannica* Professor Archibald Geikie writes: "Though we cannot hope ever to have direct acquaintance with more than the mere outside skin of our planet, we may yet be led to infer the irregular distribution of materials within the crust from the present distribution of land and water, and the observed difference in the amount of deflection of the plumb-line near the sea and near mountain chains. The fact that the southern hemisphere is almost wholly covered with water appears explicable only on the assumption of an excess of density in the mass of that portion of the planet. The existence of such a vast sheet of water as that of the Pacific ocean is to be accounted for, says Archdeacon Pratt, by the presence of some excess of matter in the solid parts of the earth between the Pacific ocean and the earth's centre, which retains the water in its place, otherwise the ocean would flow away to the other parts of the earth. The same writer points out that a deflection of the plumb-line towards the sea, which has in a number of cases been observed, indicates that the density of the

* Address delivered at Ottawa before the Royal Astronomical Society of Canada, February 27, 1908. Illustrated by lantern slides, diagrams and models.

crust beneath the mountains must be less than that below the plains, and still less than that below the ocean-bed."

In passing I may mention that my own observations for gravity in the South Sea show an excess of gravity as indicated by Archdeacon Pratt.

We shall see later what direct acquaintance or information at least we have obtained from the interior of the earth.

Up to 1839 the interior of the earth was considered to be a hot liquid molten mass, and the reasons therefor seemed very plausible:—Did not the temperature increase as we penetrated the earth either in mines or in borings; did not volcanoes give us ocular proof when they transported the flowing lava from the interior; and in connection with these, the analysis of these lavas whether from Vesuvius or Hecla or the Andes or New Zealand or Japan showed that there was a remarkable uniformity in them, leading to the conclusion that they were out of the same cauldron; then there were the hot-springs found all over the world, apparently hot because they came from the heated interior?

These reasons seemed so obviously sufficient, that their very plausibility deadened investigation, as has happened with more than one phenomenon.

Cold, unrelenting, uncompromising, impartial mathematics, is not content with plausibility only. In 1839 Hopkins of Cambridge attacked the problem, and endeavoured to calculate how far the planetary motions of precession and nutation would be influenced by the solidity or liquidity of the earth's interior. He found that the precessional and nutational movements could not possibly be as they are if the planet consisted of a central ocean of molten rock surrounded with a crust of 20 or 30 miles in thickness; that the least possible thickness of crust consistent with the existing movements was from 800 to 1000 miles, and that the whole might even be solid to the centre, with the exception of comparatively small vesicular spaces with melted rock.

In treating of the interior of the earth we shall do so under the following headings: Density; Figure of the Earth; Tides; Variation of Latitude; and Earthquakes.

Density or Specific Gravity.—If we compare the weight of a cubic foot of any substance with an equal volume of water we obtain directly the density or specific gravity of the former, as water is the unit of measure. Now this process can be followed for all substances or matter on or near the surface of the earth, but as we cannot penetrate any distance into the earth we cannot directly measure the density for such depths, nor weigh the earth as a whole. However to arrive at the latter several methods are open to us. Here we may first postulate Newton's Law of Gravitation, which declares that "any particle of matter attracts any other particle with a force inversely proportional to the square of the distance between them and directly to the product of their masses."

Our first method is that of the deflection of the plumb-line—or Mountain Method, first applied by Maskelyne in 1774.* Now the direction of the plumb-line is the resultant of all forces acting upon the freely suspended bob or mass. In reality we do not use a plumb-line, but which amounts to the same thing, we use a very sensitive level which owes its position of equilibrium exactly to the same causes as does the direction of the plumb-line. What Maskelyne did was this, he made a topographic survey of Mt. Schehallien and its surroundings, a volumetric survey one may term it, furthermore he determined what the average density of the mountain was, this combined with the volume gave him the mass with which he had to deal outside of the earth itself. Observing, then, zenith distances on the south side of the mountain and again on the north side of it, it is evident that the two would differ by twice the amount that the mountain would deflect the plumb-line from the direction given to it by the attraction of the earth. We have in this case two forces pitted against each other, both forces subject to the same law, *i.e.*, of the inverse squares of the distances and directly as the masses—the unknown quantity being the mass of the earth. From these observations the mean density was found to be 4·5. Now this is an important

* *An Account of the Calculations made from the Survey and Measures taken at Schehallien* by Charles Hutton, F.R.S., 1779.

deduction as will be more fully shown later. Let us state our two facts just found, one is that the density directly measured on the surface was in this case 2·5, and the mean density of the earth 4·5. An interesting inference is made in the above-quoted *Account*, p. 96, viz.: "Consequently $\frac{20}{31}$, or nearly $\frac{2}{3}$ of the distance of the earth, is the central or metalline part." As to the distribution of the density we have by this investigation no knowledge.

The next method briefly to be referred to is that of the pendulum. Now, the pendulum we may consider as an oscillating plumb-line; its action is subject to the same law of gravitation. The greater the pull or force, the more quickly will the pendulum oscillate when disturbed from its position of rest. Hence if we allow a pendulum to swing on top of a mountain whose mass and height are known, and again at the base of the mountain knowing the radius of the earth, in the relation of the equation connecting the observation the only unknown quantity is the mass of the earth, which is thus found. The weak point in this, as in the former method, is the uncertainty of the mass of the mountain, even when numbers of samples of the constituent rock have been weighed.

Another practical application of the pendulum is from observations on the surface of the earth and down in deep mines. This method involves a principle first pointed out by Newton and that is that at any point within a hollow, homogeneous, spherical shell, gravity is zero. Hence in a mine all the matter in a shell the thickness of the depth of the mine has no effect, as the mass in spheres is reduced in the ratio of the cubes of the radii, and the attraction is increased by the square of the radii, the resulting attraction varies directly as the radii. Airy observed by this method, but from the impossibility of obtaining a reliable value for the covering shell the result was not very satisfactory, being 6·56.

The most accurate method is by means of the torsion balance. This is essentially laboratory work, where all the data undergo rigorous determinations and examinations.

From the end of a fine wire, or better still a quartz fibre, is suspended symmetrically a rod having at each end a small metallic ball, each of the same mass. The first determination to be made is the so-called "torsional coefficient," *i.e.*, the resistance that the fibre offers to being twisted. This is done by giving the balls a small rotational motion and observing the time of their swing backward and forward, twisting and untwisting the fibre. The rapidity with which oscillations take place is dependent upon the fibre, the greater its resistence to torsion the shorter will be the period. Having the coefficient determined, the next step is to measure the twist or torsion produced by placing large metallic spheres of known mass on opposite sides of the small balls, and at given distances from them. By the law of gravitation the ball and sphere will approach each other, and the force which is exerted is measured by the amount of torsion of the fibre, and as its coefficient is known the force can be expressed in the ordinary units. Now the force of the earth is known, *i.e.*, we know the acceleration to be 32 feet per second per second, or 978·60 dynes, or we may express the force by saying that the pull of the earth on the small ball is, of course, its weight.

We also know the earth's radius or volume, hence its mass by comparison with the mass of those attracting spheres. As mass is the product of volume into density, we finally obtain the density of the earth, that is, the mean density. Recent determinations by this method give the density as 5·527.

Now what have we learned from these various determinations of the density of the earth? We have found that the mean or average density is about five and a half, *i.e.*, the matter of the earth is volume for volume compared with water between five and six times as heavy as water. Heavy is rather an inaccurate expression, as it implies a force, a pull; better to say, five or six times as dense as water. Mass is independent of force, weight is not.

We have learned something of the earth in its entirety, but we are after details. Although we know so far with a considerable degree of accuracy what its mean density is, yet from it we

know nothing definitely about the distribution of the matter. We might surmise or assume as probable that the density increases, perhaps following some law, from the surface to the centre, but as far as the above data are concerned it would only be a surmise. What we can say, however, with certainty is, that if the distribution of mass in the earth is not uniform, then as the density of the earth as a whole is 5·5, some of it must be greater than 5·5 and, of course, some less, as we know to be the case for matter on the surface. Let me say here that the density of iron lies between 7 and 8.

Let us consider briefly another question—the figure of the earth—and see what evidence it can furnish us of its constitution.

Newton, applying his law of gravitation and centrifugal force, deduced the flattening for a homogeneous fluid, rotating with a uniform angular velocity to be $\frac{1}{230}$, *i.e.*, the axes in the ratio of 229 to 230.

A few years later Huyghens, on the assumption that the attracting force was concentrated about the centre, found that the ratio of the axes was as 578 to 579, *i.e.*, the flattening $\frac{1}{579}$; this latter assumption is equivalent to considering the bulk of the mass of the earth gathered about the centre. We see then that for a homogeneous earth, *i.e.*, where the density is the same throughout, the flattening is about 2½ times as great as when the density is enormously greater about the centre.

Now from pendulum observations as well as from geodetic measurements the flattening of the earth has been found to be about $\frac{1}{293·5}$ (Clarke's value 1880). We see that this value falls between that of Newton and that of Huyghens, obtained under certain and different assumptions. We may infer therefore that the actual conditions in the earth fall somewhere between those assumed by Newton and Huyghens. Hence the conclusion is that the density increases towards the centre. This is an important deduction, and in the sequence of our discussion is the first direct inference of the distribution of the mass within the earth.

In default of knowledge, Laplace assumed, as an hypothesis, the law of compressibility of the matter of which, before its

solidification, the earth consisted, to be that the increase of the square of the density is proportional to the increase of pressure. Now the phenomena of precession and nutation are dependent upon the distribution of the mass of the earth, *i.e.*, upon the moments of inertia about the polar and equatorial axes. If we compute the moments of inertia about these two axes we obtain the constant $(C - A)/C$, where C and A are respectively the moments of inertia about the polar and equatorial axes, we find the value to be ·00327, or $\frac{1}{305}$. The moments of inertia of the earth as an ellipsoid about the principal axes are $C = \frac{a^2 + b^2}{5} m$ for the polar axis, and $A = \frac{b^2 + c^2}{5} m$ for the two equatorial axes. Taking the earth as an oblate spheroid $a = b$, hence $\frac{C - A}{C} = \frac{a^2 - c^2}{2a^2} = \frac{e^2}{2}$ where e = eccentricity.

As will be seen from the expression it is equal to the flattening or compression approximately $\left(f = \frac{e^2}{2} + \frac{e^4}{8} + \frac{e^6}{16} + \ldots\right)$ or to one half of the square of the eccentricity of the earth, and as this latter quantity is known from the other data we find the two to be fairly accordant, from which it might be inferred that Laplace's hypothesis is verified. But it is necessary not to overlook a very important point, and that is, that the density may only to a degree be dependent upon pressure. The density not only may, but very probably is, dependent largely in the depths of the earth on inherent molecular aggregation; and instead of a homogeneity of material throughout the earth, subject only to the respective pressures at different depths, we probably have to deal with matter inherently of different specific gravity.

There is another phenomenon upon the earth which gives us some clue as to the plasticity or rigidity of the earth, it is the tides. Tidal action through the law of gravitation plays a very important factor in the cosmos, but we can now occupy ourselves, and that but very briefly, only with our own planet. In all or nearly all physical investigations the difficulty of absolute deter-

minations is encountered. The determinations all pass through the phase of relative measures before the absolute value is arrived at. So it is with the tides.

If we observe the height of the tide at flood and again at ebb, we naturally infer that because water is a fluid, is mobile, it answers or responds to the call or attraction of the Moon and Sun, which the earth as a solid does not. This last statement, however, begs the very question, that of an unyielding solid, which we wish to consider. Let us consider for a moment the earth as a plastic mass. It must be evident then, that although the Moon and Sun would exert their attractive force just as much as before, the phenomenon of tides would practically disappear, for under gravitational stress the land would rise and fall just as the water, and hence their relative position would remain the same. As the land became stiffer, *i.e.*, offered more resistence to being pulled out, tides would appear, until perfect rigidity set in when the maximum rise and fall of the water would occur. We see therefore that the actual tides as we observe them, are a measure of the rigidity or elasticity of the earth. A fluid interior of the earth, as the word fluid is ordinarily understood, seems therefore impossible from the consideration of tides. The gravitational stresses and consequent strains on the interior would continually break up the thin rigid crust of the earth with every revolution of the Moon around the earth. Lord Kelvin found that if the earth had only the rigidity of glass then the tides would be only $^2/_5$ what they would be on a rigid earth, and similarly if the earth had the rigidity of steel then the tides would be $^2/_3$ those of an inelastic earth. As Lord Kelvin says in his closing words on the subject: "On the whole we may fairly conclude that, whilst there is some evidence of a tidal yielding of the earth's mass, that yielding is certainly small, and that the effective rigidity is at least as great as that of steel." *

We will now pass to another consideration involving the nature and distribution of the mass of the earth—it is that of the variation of the pole or poles of the earth.

* *Natural Philosophy*, Vol. II., p. 460.

It is now over a century since Euler established that in any mass-system the axis of free rotation about the centre of gravity can only remain fixed in the system when it is coincident with one of the principal axes of inertia passing through the centre of gravity. Moments of inertia for a solid are generally referred to three principal axes passing through the centre of gravity ; for one of them the moment of inertia is a maximum, that is, the summation of the products of every particle of mass by the square of its respective distance from that axis is a maximum ; for another, at right angles to the former, the moment of inertia is a minimum. The third axis is at right angles to the plane containing the other two. In the ellipsoid the principal axes would be coincident with its semi-diameters a, b, c. In the oblate spheroid, a figure of revolution, one that is generally assumed in the discussion of the earth, the axes a and b of the ellipsoid become equal, *i.e.*, the equator is a circle. As stated, Euler showed the stability of the axis of free rotation only then obtains when it coincides with one of the principal axes of inertia. Now in the case of the earth whose shape is due to the very fact of rotation, the principal axis of inertia with which the axis of rotation must coincide to ensure stability must be the polar or shorter one, the one for which the moment of inertia is a maximum.

It may be remarked that for a sphere in which all the diameters are equal, the moments of inertia about any axis through the centre are equal and hence the position of any axis of rotation about the centre may be considered unstable, as the slightest unsymmetrical displacement of mass would produce a permanent change of the position of the rotation axis. Of course the moment a spherical fluid sphere begins to rotate about any axis, the sphere will through the influence of centrifugal force begin to flatten, that is, the axis of rotation will shorten and the axes perpendicular thereto will lengthen. What shape the sphere will take is strictly definable when its period of rotation and the density of the fluid are known.

We see that in the evolution of a spherical liquid or plastic body, when rotation about a diameter is given to it, the axis of rotation will gain stability by the changing form of the body, due to the centrifugal force, and this stability must necessarily continue as long as the mass adjusts itself to the axial rotation, that is, there will be perfect coincidence between the axis of free rotation, and the principal axis of inertia passing through the poles ; in short, there will be no variation of the pole. When in the course of time the plastic mass begins to cool and stiffen, it cannot so readily adjust itself to the demands made by the axial rotation. From what we know of the surface and crust of the earth, of faulting ; of elevation and sinking of masses ; of extrusion and intrusion of lavas, it is obvious that displacements of mass have taken place, and some of them under violence, so that it is reasonable to suppose that at times at least the coincidence between the axis of rotation and the respective axis of inertia would be disturbed. Now according to Euler's theory in this event the axis of rotation will relatively to the solid have a conical movement about the above principal axis of inertia, while pointing to the same fixed point in the heavens, *i.e.*, the declination of the stars is not affected, and its period will be dependent upon the dimensions of the earth and the relation of the principal moments of inertia about the polar and equatorial axes. The period, expressed in terms of the principal moments of inertia, is equal to $\frac{C}{C-A}$. Expressing this numerically we find the period to be about 306 days, say ten months. It is to be borne in mind that this result applies to a perfectly rigid earth, it is obtained simply from a displacement of mass causing a minute divergence between the axis of rotation and the principal axis of inertia. Now the result of this divergence means that the latitude of every place on the earth would go through a cycle of change in 306 days.

Astronomers recognized the validity of Euler's reasoning and examined the records of observations to see if such a period was traceable from latitude observations or meridian circle readings, but they failed. The examination revealed that whatever

the fluctuation of latitude, it was confined to a fractional part of a second of arc. The precessional effect upon the axis of the earth, that is, the effect from external forces, the attractions of the Moon and Sun, is to carry the pole around the heavens in about 26,000 years, the axis describing the surface of a cone whose vertical angle is nearly 47°, being twice the inclination of the plane of the equator to the plane of the ecliptic. We shall find that this external influence upon the position of the axis of rotation within the earth is very small, for the precessional effect would be represented on the earth in linear measure by the Arctic circle, and this divided by the number of days in 26,000 years would give the circumference of the circle described by the rotating axis, and this is found to be five and a half feet, which is equivalent for the radius in angular measure of 0″·009, a quantity wholly unrecognizable by observation, so that one may almost strictly say, that the position of the axis of rotation in the earth is not influenced by the change of position in space. However in a quite opposite manner do the changes and distribution of mass within the rotating body act. In this case the change of position of the axis of rotation in the body is predominant, while those in space are secondary and vanishingly small. The following may therefore be almost rigorously stated, that in consequence of the change of distribution of matter of the rotating mass no perceptible change of the position in space of the axis of rotation results from a change in position of the axis of rotation in the body.

Dr. Küstner was the first to show, from his own observations in Berlin, that the latitude had decreased 0″·20 from 1884 to 1885. In 1888 the subject of variation in latitude was taken up by the International Geodetic Commission, and it has actively been prosecuted ever since under the direction of Helmert.

Since 1900 with similar instruments and methods continuous observations have been made at the six international stations—Gaithersburg, Cincinnati, Ukiah, Mizusawa, Tschardjui and Carlo-Forte, all on or very near the parallel of 39° 08′.

A name that will always be most intimately associated with the proof of the change of latitude is that of Chandler, who found that the period was not 306 days, according to Euler's theory, but 427 days. Subsequent to his first announcement in 1891, Chandler examined an enormous amount of material, and as Professor Abbot writes, "From this great array of evidence the fact of the wandering of the pole was not only clearly defined, but also the variation of its period and amplitude came out without question, and an insight was gained, as to the cause of this baffling phenomenon, as follows: The observed variation of latitude is the resultant curve arising from two periodic fluctuations superposed upon each other. The first of these, and in general the more considerable, has a period of about 427 days, and a semi-amplitude of about 0″·12. The second has an annual period with a range variable between 0″·04 and 0″·20 during the last half century . . . . As the resultant of these two motions, the effective variation of latitude is subject to a systematic alternation in a cycle of seven years duration, resulting from the commensurability of the two terms. According as they conspire or interfere, the total range varies between two-thirds of a second, as a maximum, to but a few hundredths of a second, generally speaking, as a minimum."

Now this deviation of 121 days from the theoretical value of 306 days is intimately bound up with the interior of the earth, with its rigidity: as already stated the 306 days pertain to a perfectly rigid earth. The investigation in this respect has led to the result, as stated by Professor Wiechert that the resistance of the earth to deformation is twice as great as that of steel, as we know it. We see then that the variation of latitude tells us something definite about the interior of the earth.

Professor Turner in his "*Astronomical Discovery*" refers to the effects of the wandering of the poles, and says that we should expect to find a swash of the ocean, even if very small, and also that "the little cracks of the earth's skin, which we call earthquakes are more numerous when these unbalanced vibrations are at their maximum; that is to say, about once every seven years,"

—*i.e.*, that earthquakes are in a measure dependent upon the behavior of the axis of rotation. On the other hand a few investigators believe the earthquakes are accountable, to some degree, for the variation of the axis of rotation by the displacement of mass within the earth. This rather extended reference to the wandering of the pole within the earth is introduced to show its connection with the interior of the earth, its rigidity, its elasticity.

We now come to another source of evidence regarding the interior of the earth, it is the principal one that we have for consideration to-day.

Earthquakes and the Interior of the Earth.—Let us tarry for a moment with the word wave as understood in physics. A wave is a vibration propagated from particle to particle through a body or elastic medium. We may distinguish different classes or types of waves: gravitational, as in water; longitudinal waves or waves of compression and dilatation, such as manifested in sound; and lastly transverse, as are manifested in the propagation of light. It is certain that the hypocentre or origin of earthquakes is not situate at any great depth compared with the radius of the earth. From deductions based on direct observation within the epicentre, or area within which destruction takes place it appears that probably thirty miles is the very extreme depth at which earthquakes occur. Hence the study of the interior of the earth can not be made from any records within the epicentral region, for the waves received there can not come from or through any greater depth than that of the hypocentre which, as has been said, is within say thirty miles. It is evident we must get farther and farther away to obtain greater and greater depths for the path of those earthquake waves that enable us to study the interior of the earth. Let us consider the first impulse recorded by a number of seismographs or earthquake instruments situate at varying distances of some thousands of miles from the seat of disturbance. Each record would show an abrupt and rapid oscillation. Let it be granted that the origin is known and hence the distance along the surface of the earth and

along the chord to each station would be known. Now we can either assume the time of the occurrence of the quake to be known, as is nearly always the case when the epicentre is in inhabited regions, as was the case in San Francisco, Valparaiso, and Kingston, or we may compute it indirectly from the observed times of arrival of the shock at the various stations. The former assumption suits our purpose better. Now see what our problem looks like. It is something like this analogy: Many trains leave Ottawa at the same time in different directions; one arrives at Halifax at a certain time, one in Washington, one at St. Louis and one at Vancouver. If we divide the distance travelled by each, by its respective time consumed, we will get the average speed or rate of propulsion. Granting the same motive power, the road that had the least resistance, the easiest grades would show the highest speed. The distance travelled then combined with the time gives us the average velocity. Now let us return to our earthquake record where we have given the accurate time of transmission, for it is the difference between the time of the actual occurrence of the quake and the time the shock arrives. With the distance our *a priori* knowledge is not so certain for we may say that there are an infinite number of distances between any two points upon the earth, it depends upon the path that the particular wave, which has recorded itself, has taken to reach us from the origin. Torricelli tells us that "nature abhors a vacuum," and similarly nature abhors the roundabout way but follows the line of least resistance at hand. Have you ever followed a mountain stream and seen how it picks out the route of greatest descent, being the easiest and quickest to get down to the valley? Similarly must be the route of our first shock, or preliminary tremors as they are technically called. Now we are safe in assuming that there is some law of increase of density, be it due to pressure or molecular arrangement or both, as we go down in the earth for a considerable depth anyway. This assumption combined with our knowledge of the behavior of different solids of various densities for the propagation of waves leads us to the conclusion that the path of the earthquake wave

first to arrive will not be along the geometrically shortest line but along a line concave to the surface, the line along which the pulsations are most quickly transmitted. But even were we to omit the assumption of any particular law for the increase of density as we descend into the earth and treat the medium simply as isotropic we will be able to make the point that we have in view. We will take then that the particular wave travels along the chord, the shortest distance between the two points, *i.e.*, of origin and station, and this distance is accurately known, as is the time. We obtain then an incontrovertible average speed or velocity of propagation of the pulsations. Now let us return to the physical laboratory and see what information we can obtain there to enlighten our path and draw valid conclusions. We find that the speed of propagation through various substances is given, and further that the law of speed is expressed by $v = \sqrt{\frac{E}{d}}$, *i.e.*, the velocity of a wave of compression and dilatation or rarefaction in an isotropic medium is equal to the square root of the elasticity of the medium divided by its density,—or we may say that the velocity varies directly as the square root of the elasticity and inversely as the square root of the density. Increase of temperature also increases the velocity. It is generally accepted that the first preliminary tremors are longitudinal waves, while the second preliminary tremors are transverse, and the waves of the principal portion are surface waves.

When we compare various seismograms of the same quake, having noted on each the various phases, it will be found that the time interval from the occurrence of the shock to the arrival of the long-period waves is directly proportional to the arcual distance from the epicentre. Or inversely, we find for that particular kind of wave that the time interval is proportional only to the respective arcual distances from the centre of disturbance, and as the velocity is dependent upon the density of the medium, the medium, we see, must be more or less uniform, in this respect, which occurs only between two points when the path joining them lies along the surface of the earth. Hence this form of

waves must be surface waves. The average speed of these waves is 3·4 km. or 2·1 miles per second. For instance in the San Francisco catastrophe those waves took nearly 17 minutes to reach us here, an arcual distance of 35° 25′ or 3930 kilometres, velocity 3·8 km.. hence to complete the circuit of the earth would take a little more than ten times as long, or over two and a half hours.

When, however, we make comparison of the two phases of the preliminary tremors, we note two important facts, the first is, that the time interval is not proportional to the arcual distance, as it is for the above surface waves; now, the natural inference would be that the wave travels along the chord between the hypocentre and the place, and, of course, the chords are not proportional to the arcs which they subtend. On closer examination of the records there will still be a small outstanding difference after making due allowance for the ratio of the chords, that is, the farther place shows the greater velocity, or which comes to the same thing, the time interval for the farther place is relatively shorter than for the nearer place, allowing for difference of distance along the chords. Strictly speaking these chord distances are only applicable in an isotropic medium, in an æolotropic medium we would find the path concave to the surface of the earth, which is really the condition which obtains. This further speed we find attributable to the greater depth, and hence greater density and elasticity of matter through which the waves reaching the farther stations travel. From the relationship which we have shown to exist between velocity, elasticity and density, and from the observed fact that the velocity increases with the depth, to within certain limits, it follows that the elasticity must increase faster with the depth than does the density. This, then, is the first fact that we note with reference to the first preliminary tremors as interpreted from different seismograms. The second is that the interval between the first and second preliminary tremors is not only not constant, but increases with the distance from the hypocentre. This fact immediately differentiates the nature of the waves. It is evident and obvious that one kind of pulsation is gaining on the other, otherwise the two recorded

phenomena would not be getting farther and farther apart, and we arrive at the conclusion that we are dealing with two different kinds of waves—with longitudinal and transverse waves. It may be opportune right here to draw a certain inference, after having seen the existence of transverse waves. While longitudinal waves, those of compression and dilatation, may be propagated in a solid or fluid, the transverse waves (those of distortion) can not be propagated in a fluid, taking the term in its ordinary acceptation. We must conclude therefore that in that sense of fluidity we cannot speak of the interior of the earth. The interior of the earth is neither liquid nor gaseous, but solid. It is to be borne in mind, and this point may well be emphasized, that this is not a speculation, as so much hitherto has been about the interior of the earth, but the direct evidence or hand-writing of messengers who have travelled through the earth, and told us their story on the seismogram. The seismograms are the Röntgen rays of the interior of the earth.

Now, as you will see from the diagram which I have constructed from available data for the San Francisco earthquake, the increase of velocity with the depth is fairly well represented by a straight line up to a depth of about one quarter of the earth's radius. The chord of this depth is subtended by an arc of about 83°. It may be remarked that an arc of 83° from Ottawa would pass close to Cairo, Egypt; Valparaiso, Chile; and the northern extremity of Japan. Beyond this depth there is no apparent increase in the velocity. Up to this point the elasticity was increasing faster than the density, but henceforth this relationship does not obtain. It would appear as if we encountered different conditions of matter.

It is found that the velocity of the first preliminary tremors increases from 7 km. per second near the surface to nearly 13 km. at great depths, where it is approximately constant. Similarly for the second preliminary tremors we have the velocity increasing from 4 km. to 7 km. per second, depending upon the depth of the path. The surface waves have an average velocity of about 3·4 km. per second.

It may be observed here that the many disturbances in Italy during the past two years must have their origin at very small depths, that is, the hypocentre must be very shallow, for, so far, no record has been obtained here of an Italian volcanic or seismic disturbance, even when the latter has been locally very destructive.

The data at hand are somewhat limited for very distant places, and the conclusions based on the latter might appear based on meagre material. However, they receive ample support from Professor Wiechert, who has paid especial attention to the subject, and who has had at his disposal a vast amount of matter. His conclusions from all the evidence he could gather, and especially from the seismological records, are that the earth is composed, essentially of a stony layer for about a quarter of the diameter, and the interior is a core, most probably of iron. We cannot on this occasion enter into the many other questions connected with our discussion. Volcanoes, which are a phenomenon apart from earthquakes, may be said to be mere pustules in the skin of the earth and are not part of an interior liquid mass or magma, for the latter does not or cannot exist.

I think it must be admitted that what has been presented as evidence by earthquakes, or rather their seismograms, about the interior of the earth, has been of a most positive and in many respects conclusive character. And we are but at the beginning of this new science of Seismology in unravelling the story of the structure of the earth and of its behavior. Although there is a fairly clear idea of the propagation and nature of the waves issuing from the hypocentre, or more strictly speaking the hypo-area, for the seismic disturbance does not issue from a point, but rather an area or volume is involved, yet there remains much to be learned about these waves. Then, too, the separation on the seismogram of the part due to the motion of the pendulum, which is supposed to be at rest, from the earth movements due to the quake, is a matter of import. But for all the difficulties involved, we must not lose sight of the fact that the seismograms have the data for a complete solution and determination of all the quantities involved in producing the records. The Rosetta stone is yet

to be found for a complete interpretation of the hieroglyphs of the seismogram. When our instruments are made more sensitive, when their time-record is improved, when we can assure ourselves on various seismograms of the identity of the record of one and the same impulse from the hypocentre, say that every seismogram considered shows the impulse from the first wave-front, then, from resulting observation equations, not only will the accurate properties of matter of the interior of the earth at various depths be determined, but eventually also deviations therefrom on particular paths along which the impulses travel, just as our pendulum observations now are mainly utilized for detecting deviations from the theoretical value of gravity; we shall be able to differentiate velocities for the same distance but over different routes, *i.e.*, coming from different hypocentres; for favorably situated stations along a mountain chain, the "roots" of the mountains may reveal their characteristics, that by other methods have been inferred.

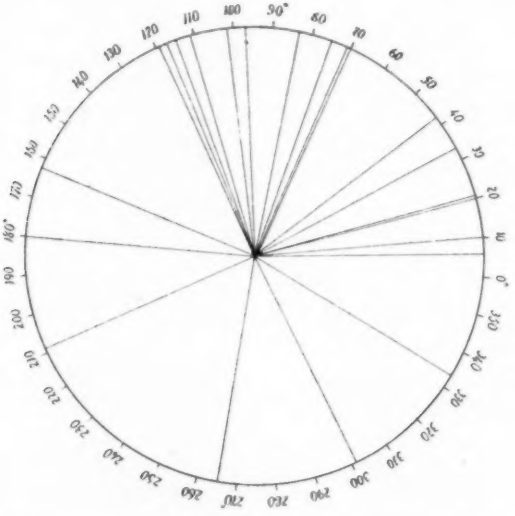
Seismology has taken firm root and the outlook for the future is bright, it holds the key to unlock the contents of the treasure vault below us. Earthquakes have already told us much of the interior of the earth and much more is in store.

THE ORBITS AND "VELOCITY-CURVES" OF SPECTROSCOPIC BINARIES

By J. Miller Barr

I.

IN looking over the published papers on spectroscopic binaries, it will be remarked that the "velocity-curves"—as hitherto drawn for these objects—are often unsymmetrical. A closer examination reveals a curious *general similarity* in the form of



The radial lines represent the values of ω, (*i.e.*, the computed longitude of periastron), for twenty-three spectroscopic binaries. See accompanying table.

such curves—the *ascending* branch of the curve, with few exceptions, being of greater length than the *descending* branch. This fact, although of great theoretical interest, seems to have been hitherto overlooked by astronomers. Its significance will be apparent from an inspection of the diagram and table given below.

LIST OF SPECTROSCOPIC BINARIES.

Star	P	e	ω	K	Reference
	d			km.	
α *Andromedæ*	100. ?	. . .	[0° – 180°]	. . .	*Astroph. Jour.*, *20*, 146, 1904.
Polaris	3·9683	. . .	[0 – 180]	3·0	" " *14*, 52, 1901.
β *Arietis*	107.0	0·88	19·7	32·6	" " *25*, 320, 1907.
Capella	104·022	0·016	117·3	25·76	" " *14*, 263, 1901.
η *Orionis*	7·9896	0·016	42 16′	144·75	" " *17*, 68, 1903.
δ *Orionis*	5·7325	0·103	33 19	100·85	" " *19*, 268, 1904.
ζ *Tauri*	138·	0·180	9 45	14·95	" " *22*, 115, 1905.
γ *Geminorum*	[3·5y ?]	. . .	[0° – 180°]	. . .	" " *22*, 84, 1905.
ζ *Geminorum*	10·154	0·22	333·	13·2	" " *13*, 90, 1901.
α_2*Geminorum*	9·2188	0·503	265·35	13·56	" " *23*, 351, 1906.
κ *Cancri*	6·393	0·149	162 16	67·8	" " *25*, 315, 1907.
α *Carinæ*	6·744	0·18	115·84	21·5	" " *26*, 268, 1907.
κ *Velorum*	116·65	0·19	96·23	46·5	" " *26*, 271, 1907.
η *Virginis*	71·9	0·254	180 0	26·8	" " *26*, 282, 1907.
Mizar	20·6	0·502	101·3	142·	" " *13*, 324, 1901.
α *Draconis*	51·38	0·43	19·	48· ±	*Jour. R.A.S.C.*, *1*, 237, 1907.
X Sagittarii	7·0118	. . .	[0° – 180°]	. . .	*Astroph. Jour.*, *25*, 330, 1907.
Y Ophiuchi	17·1207	0·10	209·2	8·5	" " *25*, 330, 1907.
W Sagittarii	7·5946	0·320	70·0	19·5	" " *20*, 149, 1904.
μ *Sagittarii*	180·2	0·441	74 43	64·5	" " *26*, 157, 1907.
χ *Draconis*	281·8	0·423	119·0	18·15	" " *11*, 131, 1900.
β *Lyræ*	12·908	0·07	83·4	181·05	" " *6*, 328, 1897.
U Aquilæ	7·0240	. . .	[0° – 180°]	. . .	" " *25*, 330, 1907.
η *Aquilæ*	7·176	0·48)	68·91	20·59	" " *9*, 59, 1899.
S Sagittæ	8·3832	. . .	[0° – 180°]	. . .	" " *20*, 231, 1904.
θ *Aquilæ*	17·17	0·725	20·	52· ±	*Jour. R.A.S.C.*, *1*, 357, 1907.
T Vulpeculæ	4·4358	0·43	111·	17·6	*Astroph. Jour.*, *25*, 330, 1907.
δ *Cephei*	5·366	0·46	[0° – 180°]	20·5	" " *1*, 160, 1895.
η *Pegasi*	818·0	0·155	5·61	14·20	" " *14*, 20, 1901.
λ *Andromedæ*	20·546	0·086	301·0	7·07	" " *24*, 345, 1906.

NOTE.—The elements refer to the *brighter* component of each system, except in the case of Mizar (ζ *Ursæ Majoris*), where the value of K is that of the *relative* orbit.

The table includes all stars (so far as known to the writer) for which the "velocity-curve" appears to be certainly unsymmetrical. It contains, for each star, the computed elements P, e, ω and K, except in a few cases where such data are not available.*

* For α *Andromedæ* and γ *Geminorum* only the general form of the oscillation.

Of the thirty stars included in this table there are but *four* for which the values of ω (as calculated) lie between 180° and 360°. For these four stars we have in each case,

$$D > I,$$

where D denotes the time-interval during which the star's "radial velocity" is *decreasing*; I the interval during which it is *increasing* (algebraically). For the remaining 26 stars $D < I$, except in the case of η *Virginis* (bright component), where $D = I$, corresponding to $\omega = 180°$.*

The apparent grouping of the periastron about certain values of ω is a yet more striking feature, which is clearly shown in the annexed diagram. That such a distribution of the apses really exists is, of course, very improbable—so improbable that we are certainly justified in seeking for a different explanation of the observed facts. In other words, the elliptic elements, e and ω, as computed and published for the orbits under notice, are probably illusory; the "observed radial velocities," upon which they are based, being vitiated by some neglected source of systematic error.†

It now remains to point out the probable nature of this source of error. Two distinct hypotheses are suggested, viz.:

(1) The spectrum-lines, for the stars under notice, are

curve has been found. The elements of *U Aquilæ* and *X Sagittarii* are as yet unpublished. In the case of δ *Cephei*, Belopolsky's value for ω (272°·3), as printed in the *Astrophysical Journal* (February 1895), is erroneous. For the benefit of readers unversed in this subject it may be added that P denotes the period of revolution; e the eccentricity; ω the longitude of periastron, reckoned from the ascending node; K the "single amplitude," $2K$ the total range in the star's "radial velocity."

* Excluding those stars for which $e < 0{\cdot}10$, we find:

$D = I$ for one star,
$D > I$ " 2 stars,
$D < I$ " 21 "

† The period P may of course be relied upon; and it is satisfactory to note that this element has in many cases been determined with a high degree of precision. In cases such as that of Capella, for which the oscillation-curve is almost symmetrical, the computed values of K and $a \sin i$ are doubtless nearly correct.

periodically shifted from their normal positions, owing to exceptional conditions of pressure or temperature in the star's photosphere, or its surrounding atmosphere.

(2) The disks of the stars under notice are not uniformly bright. The distribution of surface-brightness in *longitude* is for each star, unequal, and for some stars, distinctly unsymmetrical. Such conditions, combined with rapid axial rotation, would result in a more or less unsymmetrical broadening of the spectral lines. The *effective* result would be a periodic shift of these lines, as measured on the spectrograms.

The possible source of error referred to in (1) has been made the subject of careful investigation.* In a few cases, such as that of *Mira Ceti*, there is evidence that a "physical shift" of certain lines in the star-spectrum does actually occur.† On any rational theory, however, it is very unlikely that physical causes would give rise to *periodic* displacements, affecting *in a similar degree* the positions of several or many lines (due to various elements) in the spectrum of a star.

The second hypothesis rests upon a much more substantial basis. It was suggested by a perusal of Dr. Albrecht's paper on "A Spectrographic Study of the Fourth-Class Variable Stars *γ Ophiuchi* and *T Vulpeculæ*."‡ In that paper, Dr. Albrecht calls attention to a most important relation which exists between the light- and velocity-curves of *δ Cephei* variables. "In every observed case," he remarks, "light-maximum and greatest velocity of approach occur within one-fifteenth of the period of each other. Likewise minimum brightness and greatest velocity of recession occur at the same time."

*Among recent papers dealing with this subject are those of Humphreys (*Astrophysical Journal*, *26*, 18, 297, 1907), Larmor (*Ibid.*, *26*, 120) and Duffield (*Ibid.*, *26*, 375). The researches of Julius on "dispersion-bands," should be considered; also the possibility that a shift of the spectral lines may result from electrical or magnetic conditions in the stellar atmosphere.

†See papers by Campbell (*Astrophysical Journal*, *9*, 31, 1899), Stebbins (*Ibid.*, *18*, 341, 1903) and Plaskett (*Jour. Roy. Ast. Soc. Can.*, *1*, 45, 1907).

‡*Astrophysical Journal*, *25*, 330, 1907.

An inspection of the accompanying table will show that it includes eight variable stars of the *δ Cephei* type.* Their orbits, according to the published elements, are more or less decidedly elliptic—the computed values for the eccentricity *e* varying from 0·10 in the case of *Y Ophiuchi* to 0·489 in that of *η Aquilæ*. If we assume that these orbits are in reality nearly circular,† it would appear that the observed facts—as graphically summarized in the light- and "velocity"-curves—may be explained on the second hypothesis outlined above. The unsymmetrical distribution of light on the discs, as postulated for these stars, is probably due to tidal action, modified by an unequal angular rotation in different latitudes, such as exists in the solar photosphere.

Accepting this theory, we must suppose that the *preceding* side of the revolving star is, on the whole, more luminous than the opposite hemisphere.‡ A similar state of things seems to exist in certain variable stars of the Algol type—notably *S Cancri*, *U Coronæ*, *δ Libræ*. For such stars, the rise from minimum to maximum brightness is less rapid than the fall from maximum to minimum. This fact would seem to admit of only one probable explanation, which is in harmony with our present theory, viz., that the *advancing front* of such a star, as it traverses its orbit, is more luminous than the *rear* side.§

Further evidence tending in the same direction is afforded by certain facts of observation, which are here summarized:

* The light-curve of one of these stars, viz., *W Sagittarii*, is apparently subject to distinct changes in form. According to Schmidt's observations (1866–76) it was formerly of the *δ Cephei* type; but the Harvard observations of 1898 give a light-curve in which the *decrease* of light is more rapid than the *increase* (*H. C. O. Annals*, *46*, Part II).

† This assumption, for theoretical reasons, seems highly probable when the shortness of the periods is considered (Cf. Darwin and See on the theory of tidal evolution).

‡ Cf. Curtiss (*Astrophysical Journal*, *20*, 186, 1904), Albrecht (*Ibid.*, *25*, 330, 1907), and Loud (*Ibid.*, *26*, 369, 1907).

§ Strictly speaking, this remark applies only to that hemisphere of the star which is turned towards the earth about the time of minimum brightness.

(*a*) Distinct irregularities occur in the "velocity-curves" of certain variable stars, and these correspond with inequalities in the *light*-curves of the stars.

(*b*) Broad, unsymmetrical lines have been noted in the spectra of several binaries—notably *δ Orionis*.

(*c*) In the interesting case of *η Virginis*,* Ichinohe has obtained *dissimilar* velocity-curves from measures of spectrograms taken, respectively, with full dispersion and with a single-prism spectrograph. This remark applies to the brighter member of the system. For the faint component, a *double* curve having the same period (71·9 days) has been found. Moreover, the deduced "radial velocity of the centre of gravity" is, for the bright component, −0·4 km., and for the fainter star +30 km.—a most significant difference.

The further discussion of this interesting subject is reserved for a future paper. In the latter I hope to deal with certain details of the theory here advocated,† and to offer some hints concerning practical methods for the separation of effects due, respectively, to axial rotation and orbital revolution of the stars under notice.

ST. CATHARINES, ONT.,
February 10, 1908.

NOTES ON MR. BARR'S PAPER

I. BY W. F. KING

IT seems remarkable that out of thirty orbits measured, only four should have their periastron nearer to us than the focus, a circumstance the odds against which, on the hypothesis of random arrangement, are of course very great.

Observed facts are, that the curve obtained by plotting the radial velocities as ordinates, with the times for abscissas, accords

* *Astrophysical Journal*, *26*, 282, 1907.

† One interesting consequence of this theory may be noted here, viz., that many—perhaps all—spectroscopic binaries are variable in brightness; though the range of this periodic light-change must, in general, be small.

well in form, at least in the great majority of orbits, with what it should be on the hypothesis of simple elliptical motion, and that this curve changes little, if at all, even after many periods. It is hardly to be supposed that such powerful tidal action as it is necessary to assume should result in a change of the apparent velocity in one part of the orbit, amounting to many kilometres per second, and still leave the general velocity curve so closely in accordance with theoretical form. Again, this powerful tidal action ought to have an effect in altering the elements of the orbit after not many complete periods; such change has not been observed.

The alternative supposition is that the displacement of the lines occurs, not in connection with the place of the body in its orbit, but from some cause not connected therewith. Under such supposition, what is the probability that in so large a proportion of the total number of cases, it should deceive us in the same way?

II. By J. S. Plaskett

Unsymmetrical Velocity Curves (First Paragraph).

Velocity curves are never true sine curves or symmetrical, except when $e = o$.

The main answer to the views expressed in the paper I think lies in the fact that the velocity curves for many of the stars under discussion have been determined from measures of plates made with high-dispersion spectrographs on spectra of the second type, which admit of very accurate measurement.

The probable error of velocity determinations is in most cases not more than a kilometre, leading to a very accurate drawing of the velocity curve. In every case the ephemeris or velocity curve drawn from the computed elements, (assuming a simple elliptic orbit without perturbations or disturbances), agrees very closely with the observations. If there were any such secondary effects as Mr. Barr speaks of it is highly improb-

able, to say the least, that their effect combined with the action in the orbit, presumably elliptical, would result in a velocity curve corresponding, within the errors of observation, to a simple elliptic motion of the bright star around the centre of gravity of the system.

Hypothesis (2) (Page 73).

"Rapid axial rotation." This presumably refers to more rapid rotation than the period of revolution, and the secondary curves thereby introduced would be irregular, so that the resultant curve due to elliptic motion and the axial rotation of the non-uniformly lighted star would be very irregular in outline and could not possibly result in changing the value of ω. Such has not appeared in any published curve. If on the other hand we assume a period of rotation and revolution equal, then, unless the dimensions of the body are comparable with the dimensions of the orbit not much change would occur in the resultant velocities. Further, if the *preceding* side is more luminous, would not the changes in velocity thereby produced be similar on each side of the point of zero velocity (when the star is moving parallel to the line of nodes) and result only in increasing K without changing ω appreciably?

Finally.

It must be remembered that only the inclination of the axis to the line of sight is known and it may lie in any direction whatever in the conical angle thus described. Furthermore, if the absolute directions in space are considered, it is evident that there can be no such grouping as is shown in the paper.

For example, if two stars about 12 hrs. apart have the same ω then their apses are pointed in opposite directions. Probably if all the known binaries were plotted on a globe with cones corresponding to the direction of their apses this direction would be found quite irregular and without any preponderance, other than accidental, towards any one direction.

SUPPLEMENTARY NOTE BY MR. BARR.

In dealing with a new and difficult subject, such as is brought forward in my paper on "The Orbits and 'Velocity-Curves' of Spectroscopic Binaries," it was almost inevitable that some slips and omissions should occur. Thus, in my original MS., the wording of paragraph "(2)," which defines the influence of axial rotation for a revolving star, was imperfect. This paragraph has, therefore, been carefully amended. As regards my tabular list of binaries, the case of Mizar was regarded as exceptional; the components being roughly equal in brightness and the orbital elements merely relative.* Hence it is uncertain whether the computed value of ω should be 101°·3 (as given by Vogel) or 281°·3. This fact was, unfortunately, overlooked when my table and the accompanying diagram were being prepared. The interesting case of ι *Orionis* (for which provisional elements were computed at the Dominion Observatory) also escaped my notice (*Jour. R. A. S. C.*, Nov.–Dec., 1907, p. 373).

Some results derived from a later investigation of this subject are given below (Cf. *Popular Astronomy*, April, 1908, p. 259):

Let us take the case of a rotating star which revolves in a circular orbit about the centre of gravity of the system; the axis of rotation being perpendicular to the orbit-plane, and the star rotating in the same direction as it revolves. Let us further assume that the star's surface-brightness at any point depends upon the *height of the tide* (due to a revolving satellite) at that point; *high* tide corresponding to minimum and *low* tide to maximum surface-brightness. (The axis of symmetry is here supposed to coincide with the radius vector). On these assumptions, our general expression† for the star's *apparent radial*

* Mizar must now be regarded as a quadruple system, a fourth component having recently been brought to light at the Yerkes Observatory. (*Astrophysical Journal*, March 1908, p. 166).

† In this formula i' is the inclination of the star's equator-plane and ν the longitude of its ascending node with reference to the "tangent-plane" from which i is reckoned. ν is measured from the ascending node of the *orbit-plane*, *i.e.*, the point for which $v+\omega=0$.

velocity (V_s), viz.,

$$V_s = V_o + V_1 \left\{ e \cos \omega + \cos (v + \omega) \right\} + V_2 q p(e, i, i1, r, v, \omega)$$

reduces to the simple form

$$V_s = V_o + V_1 \cos \theta + V_2 F(\theta),$$

where V_o is the radial velocity of the centre of gravity of the system; $V_1 = \frac{2a\pi}{P} \sin i$ is the *constant of orbital motion*, and $V_2 = \frac{2r_o\pi}{P^1} \sin i$ is the *constant of axial motion*; r_o being the star's equatorial radius, P^1 its rotation-period (which is here regarded as the same for all latitudes), and θ the orbital longitude, reckoned from the ascending node. The form of the function denoted by $F(\theta)$ is difficult to define, depending as it does upon various complex conditions—including the absorption of light by the stellar atmosphere, as modified by tidal deformation. It is easily seen, however, that $F(\theta)$ is *positive* in the first quadrant and *negative* in the second quadrant of longitude; being numerically smaller for corresponding positions in the third and fourth quadrants. Also, $F(\theta) = 0$ when θ is 90° or 270°, and

$$F(180° - \theta) = -F(\theta),$$
$$F(360° - \theta) = -F(180° + \theta),$$

where θ is taken in the first quadrant.

I have, tentatively, drawn several velocity-curves which correspond to the second formula given above. These theoretical curves are of the general type represented in my paper by the relation $D < I$. They show one peculiarity which should be noted here, viz., a more or less perceptible "hump" or secondary maximum in the longer or ascending branch of the general curve. Similar features are shown in the oscillation-curves of certain variable stars.

The influence of tidal friction is now under investigation. It will suffice to state here that a *lagging* of the stellar tidal wave (such as exists in terrestrial tides) would give rise to an oscillation-curve in fair general agreement with curves derived from spectrographic observations.

The known facts relating to the *δ Cephei* variables and to some Algol variables (as cited in my paper) make it almost certain that the surfaces of these stars are by no means of uniform brightness. For such stars, therefore, the *axial motion effect* (*i.e.*, the displacement of spectral lines due to the star's rotation) is, in all probability, quite appreciable. Thus the theory under notice may be said to "rest upon a substantial basis" (*Popular Astronomy, loc. cit.*)

Through the Editor's courtesy I am enabled to reply here to the critical notes of Dr. King and Mr. Plaskett, as printed above.

Dr. King seems to recognize fully the weight of the observational evidence upon which the main argument in my paper may be said to rest. But he evidently attaches greater weight to the known accordance of observation and received theory, as regards the form of the stellar oscillation-curves. I have no desire to under-estimate the force of this objection; but I think there is a natural tendency to attach undue weight to the general accordance here referred to. There are *four* independent quantities—P, $a \sin i$, e, ω—which determine the outline of the theoretical curve; and in computing an orbit by the method of least squares we practically *select* and *combine* these quantities in such a manner as to secure the *best possible agreement* between our curve and the observed "radial velocities."

Dr. King does not allude to the significant *discordances* between theory and facts which, in several important cases, (*η Virginis*, *ζ Geminorum*, *W Sagittarii*, etc.) have been found to exist. As regards the "powerful tidal action" to which he refers, it seems only necessary to point out that the consequent changes would, on the theory of simple elliptic motion, be *greater* than they would be according to the writer's hypothesis.

Turning now to Mr. Plaskett's note, it will be seen that he lays great stress upon the precision of modern spectrographic measurements. It is perhaps unnecessary to say that the writer appreciates most fully the splendid progress which has been made

in this field. This progress is well exemplified by recent contributions from the Lick, Yerkes, Potsdam, and Dominion Observatories.

The argument based on the agreement of received theory with observation has already been answered in my reply to Dr. King.

In dealing with the writer's theory Mr. Plaskett says: "the resultant curve due to elliptic motion and the axial rotation of the non-uniformly lighted star would be very irregular in outline and could not possibly result in changing the value of ω." I have failed to find any basis for this statement, which is presumably due to a hasty consideration of the subject.

There is only one other point in Mr. Plaskett's criticism that seems to call for a reply. This relates to the computed positions of the periastron. My remarks on this subject had reference only to the *apparent* grouping of the periastron-points, as measured from the ascending node—a condition which Mr. Plaskett seems to have misunderstood.

It should be added that many spectroscopic binaries are now under investigation, so that further evidence bearing on this interesting subject will soon be available.

April 5, 1908.

LUNAR TIDES ON LAKE HURON

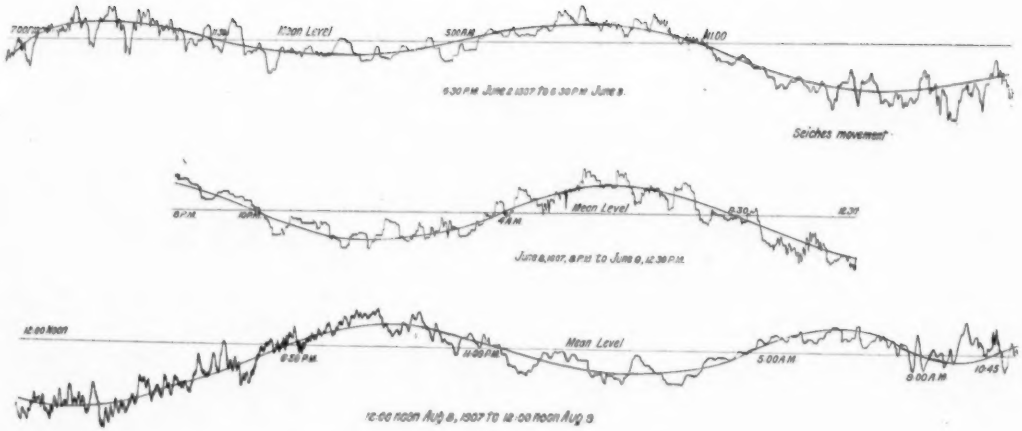
By W. J. Loudon

DURING the summer of 1907 observations were made at High Rock, Georgian Bay, by means of the apparatus already described in this JOURNAL (Vol. I., p. 181, and *Transactions*, 1905, p. 131,).

The weather was very stormy and consequently good records were rarely obtained. The best of these are shown in Figures 1, 2, 3. In the first, Figure 1, from June 2, 6:30 P.M. to June 3, 6:30 P.M., the mean curve is drawn, and also a horizontal line, showing the mean level of the water ; and the periods of low and high tide are indicated by the times marked along the line of mean level. At the right end of the curve a *seiches* movement began and the last portion of the record is therefore displaced. On June 3 the Moon was approaching its last quarter, so that there was a minimum tide, which, as measured on this curve, amounts to three-eighths of an inch.

Figure 2 shows a maximum tide, just before New Moon, which was on June 10. The period from 10 P.M. to 4 A.M., as shown on the line of mean level, gives eleven-sixteenths of an inch, which is probably high on account of the pronounced *seiches* movement in this record, and the difficulty therefore of drawing the mean curve.

Figure 3 indicates the tide of August 8–9, there being a New Moon on August 9. The latter portion of this curve gives a maximum tide of nine-sixteenths of an inch, which is not far from its true value.



FIGS. 1, 2, 3. Records of Tides on Lake Huron.
(One-fourth original size).

DETERMINATION OF THE 141ST MERIDIAN

By F. A. McDiarmid

THE treaty of 1854 between Great Britain and Russia made the 141st meridian the dividing line between the territory of the British Monarch and that of the Czar. However, nothing was done to mark that boundary until the United States secured possession of Alaska. In the years 1886–87, Mr. Ogilvie, afterwards Governor of the Yukon, made a determination of longitude by the method of moon culmination ; and a year or so later, Mr. McGrath, of the United States Coast and Geodetic Survey, occupied the same station as did Mr. Ogilvie, and employed the same method. There was quite a good agreement between the two determinations, and Mr. Ogilvie ran a traverse from his Observatory westward, and determined a point on the Yukon River at which he supposed the 141st meridian would cross. From this point a line was run a short distance north and south of the Yukon, and up to 1906 this was regarded as the Boundary line. However, doubt existed as to the accuracy of this determination ; and when the telegraph line was completed to the farthest point of Canadian territory, an opportunity was afforded of determining accurately the boundary between Alaska and the Yukon territory. With that end in view, representatives of the two countries were appointed in the summer of 1906 to make a joint determination of the 141st meridian.

In this paper, it is intended to give a short description of our great Northwest land, some of the experiences which the observer meets there, and an account of the methods employed in our longitude determinations.

For countless ages all peoples have looked upon the north as a wild and barren land, the home of the iceberg and the storm. In the past few years it has been given to a favored few to learn that the Yukon is a land of beauty, of sunny days and

clear skies, of foaming waters and green dome-shaped hills, of high cliffs and rugged granite peaks snow-crowned for all time to come. Old, yet seeming to ever change and to be always new, it is a land that charms, and seems to hold those who once visit; for the inclination is left to return and visit it again.

This vast inland empire is known to the people of the north as the Yukon, and it is the water-shed of the river of that name. The Indians call it Yu-kon-ah,—meaning mighty water,—and it is that and more. Its length is more than two thousand miles, and it drains an area of more than five hundred thousand square miles, and discharges more water into the sea than the Mississippi or the Amazon. It is seventy-five miles wide at its mouth, and at its source—at the summit of the White Pass—a child can step across. Large steamers navigate this river for eighteen hundred miles; and if you stand on the bank one hundred miles from the mouth you cannot see the other bank.

European countries in the same latitude as the Yukon, with soil less rich and climate as rigorous produce annually cattle, sheep, and horses, and of grain and vegetables thousands of bushels. To-day the very finest vegetables are grown in the Yukon, but whether it will be an agricultural country is left for the future to decide. The whole land is rich in minerals; in the five years just passed the Yukon has added to the wealth of the world one hundred and fifty millions of dollars in gold. Just here, note the great piece of fortune which fell to the United States, when it purchased Alaska from Russia for seven million two hundred thousand dollars. Since then, there have been taken from the ground hundreds of millions of dollars in gold.

In the quantity, quality and value of furs produced annually the Yukon leads the world; the valley is rich in wood, coal, petroleum and copper; thousands of acres of wild grasses grow shoulder high; in the marshes are cranberries and huckleberries, and on the slopes are wild currants, gooseberries, strawberries and raspberries; in the waters fish; in the forest game; in the ground gold; of all the lands the Yukon is among the richest. Her gold-bearing streams and the mighty Klondyke have long

excited the wonder of the mining world, and now, when these are becoming worked out, the miner's attention is attracted to the rich copper deposits near White Horse, and at the head-waters of the White river. The Pueblo copper mine at White Horse alone has a surface-showing of three hundred thousand tons of ore which will net about five dollars a ton. There are many other mines just as good, so for many years the Yukon will be famous for its mineral output.

Of those who occupied the land in days gone by—the Red Lords of the North—but few remain, the ways of their white brothers are not theirs ; and to them mean extermination. They attempt to live in the white man's house without employing any of his sanitary methods. Of those that are left, the strongest are of the Pelly, Tannanaw and Thlinkeet tribes ; they have a semi-historical, legendary history of their Asiatic origin that is very fascinating to the folk-lore lovers ; and their dogs, half-wolf, are not to be seen elsewhere in the world. The Indians of the Yukon are very similar in feature and appearance to the Japanese, but unfortunately they have but few of the progressive qualities of the Jap.

The enchanting beauty of the wide-spreading Yukon valley —its glorious sunshine and its wealth of vegetation and fruit and flowers—comes as a great surprise to one who beholds it for the first time ; and often causes the exclamation "This cannot be the north." Indeed, it is not the north land of which we have read and thought perhaps to see, but away off in the distant blue are still the mountain peaks, capped with eternal snow. No more glorious summers are to be found anywhere on the earth's surface, nor for the sportsman, can the northern autumn be excelled. Here, in the late fall you can hear the moose and the cariboo calling that it is time to get into their favorite meadows where they winter, and in the white, soft evenings the goats and sheep are heard tramping in droves and seeming to confer as to the best location for their exodus ; the grouse call softly in the thickets ; the squirrels are busy adding to their already overflowing storehouses ; and there are also the bears—black, grizzly,

brown and cinnamon—fat and sleek ; and in the sedges can be heard the ducks and geese discussing their annual excursion to the south,—truly a hunter's paradise.

People are always interested in the climate and continually ask " What is your weather ? " We have no idea of the beautiful summers of the Yukon ; we imagine that Dawson is a cold, barren place, and that even in the middle of summer, snow is seen on every hand. Such notions are indeed far from the actual facts. The months of May, June, July, August and part of September are regular paradises and are the finest we meet in any part of Canada. The visitor who expects to need heavy clothing is agreeably surprised ; the Sun shines for a large part of the twenty-four hours ; indeed, at latitude 64° 40′ there is continuous daylight during the months of June and July. To the pole more heat comes from the Sun during the 21st of June than comes to any other point on the earth's surface during any day of the year. Then, the Sun giving out his heat and light makes it a desirable resort for the summer months. It is true that ice is found only a short distance below the surface of the ground, yet the traveller is perfectly ignorant of such a circumstance, unless it be pointed out to him. The thermometer often registers 85° F. during the day, and the evenings are clear and cool for sleeping. Vegetation is very rapid ; the abundance of sunlight hurries things along ; the heat from above combined with the moisture from below causes rapid growth ; and consequently Dawson can boast of the finest vegetables in the world. Her lettuce, celery, beets, carrots, cabbages and cauliflowers are unexcelled. As we go along the streets most brilliant flower gardens meet us on every hand, and if we forget ourselves a moment we would think we were in some tropical land. But the refreshing breeze from the mountain far away recalls us to ourselves.

We have described the Yukon from the standpoint of landscape and scenery. Let us now see it from the position of an astronomer. The weather of the Yukon is ideal for astronomical work, there being but little rain during the summer months.

The experience of the writer during the season of 1906 was one cloudy night from the 13th August till the 7th September, while during the season of 1907 observations were obtained on twenty-one consecutive nights. On nineteen of these the conditions were ideal for observing. The months of June or July give us only about three or four hours each night suited for observing, but if the observer has only a few hours at his disposal daily, yet he feels confident that nearly every night will be perfect. There is very little humidity in the atmosphere at any time; and consequently the stars are very steady and clearly defined. One can observe with comparative ease a sixth magnitude star in June when there is broad daylight. Often, when we are waiting for good weather here in the east, and see night after night go by, and nothing but clouds rewarding us, then we wish that we might have a few of the clear nights of the north.

The observatory was built on the south bank of the Yukón river, about ninety-five miles below Dawson and about nine miles from Fort Egbert, Alaska. It is three hundred and fifty-two feet east of what is known as the "Ogilvie Line." The pier is a solid block of concrete about six feet deep, three feet of which are in the ground; the top of the block is twenty-seven inches long and twenty inches wide. On this was mounted one of Cooke & Sons' astronomical transits. The focal length of the object glass is thirty inches and its diameter is two-and-a-half inches, and the instrument is equipped with a Repsold Micrometer. Formerly, the ordinary spider line reticule of thirteen threads was used, but three years ago this was dispensed with, and the Repsold Micrometer took its place. A description of the micrometer will be given later in this paper. The other instruments used at Boundary were an ordinary Fauth chronograph, a Hadlock Sidereal Chronometer and a switchboard fitted with relays and other apparatus for the transmission of time signals. At Vancouver Dr. Klotz had an exactly similar outfit, as did also Mr. Edwin Smith, of the Coast and Geodetic Survey, at Fort Egbert. During the course of a night's work two time determinations were made; between these, exchanges of time

signals were carried on with Vancouver, and also with Fort Egbert. This gave two determinations of Boundary longitude. The exchange of signals with Fort Egbert was a very simple matter, the whole exchange taking only about four minutes. The Vancouver exchange, however, was not so easy ; the distance from Vancouver to Boundary is nearly two thousand miles and it was necessary to employ four sets of repeaters, one each at Atlin, Hazelton, Ashcroft and Vancouver. The telegraph line runs through a rough broken country, and, consequently, a good deal of difficulty is experienced in keeping the line in good repair. Trees are continually falling upon it and the wire is often lying on the ground ; when the trees are wet and the earth moist, the escape of electricity is considerable ; consequently, great difficulty was often experienced in getting a good exchange of signals, but with the kind assistance of the operators at the repeating stations we eventually were successful. When the line was dry and the air cool, the exchange generally took but few a minutes. On account of the nature of the country through which it runs, the Yukon Telegraph line is more or less uncertain ; it is going down continually, but the linemen along the way do their work rapidly and a break is quickly detected and soon repaired.

Another phenomenon that greatly affects the telegraph line is the Northern Lights ; when the display of aurora is by any means brilliant, it is almost impossible to keep the telegraph instruments adjusted. But if difficulties were presented in the way of our signal exchange, yet the beautiful display in the heavens quite repaid for any extra trouble The scene cannot be described; the whole sky was one magnificent picture with the scene continually changing ; as the lights chased one another across the sky a peculiar buzzing sound was heard. To one who has never been in the north the phenomenon of the *aurora borealis* is very impressive indeed.

Return once more to the Boundary Observatory. Each of our time sets consisted of twelve stars chosen from the *Berliner Astronomisches Jahrbuch.* Six stars, one north and five south, are observed with the instrument clamp east ; then the instrument

is lifted from its wyes and reversed, and another six stars are observed. The north star determines the azimuth of the instrument, and the south stars give the clock correction and collimation. Owing to irregularities of the pivots of the instrument, and also on account of change due to reversal, the azimuths of the two clamps differ slightly. To determine the effects of the errors of azimuth, collimation and level of the instrument on the time, let us assume the azimuth error to be a, the collimation c, and the level b.

Let φ = latitude of station
and δ = declination of star.

Then the effect of these errors on the time is

$$a \sin (\varphi - \delta) \sec \delta + b \cos (\varphi - \delta) \sec \delta + c \sec \delta,$$
$$\text{or } aA + bB + cC,$$

where $A = \sin (\varphi - \delta) \sec \delta$, $B = \cos (\varphi - \delta) \sec \delta$, and $C = \sec \delta$. The value of b is measured directly, and bB applied to the star's time of transit. The values of a and c and δT (clock correction) are deduced from each set of (twelve) observation equations by the method of least squares. Of course, the best time results are given when there are no effects from either azimuth or collimation; or, in other words, when the ΣA in the different clamps is nearly zero, and when the ΣC is also zero In the north it is almost impossible to get such a state of equilibrium. The latitude of Boundary is 64° 41′, and a star of greater declination than 83° is not suitable for observing on account of its slow motion. The A factor for a star of 80° declination is only $-1{\cdot}57$. It is almost impossible to get five south stars the sum of whose azimuth factors does not exceed $+1{\cdot}57$. Of course, the sum of the C factors in the different clamps can be made to balance one another; but the disadvantage in time work in the northern latitudes, is the difficulty of obtaining well-balanced sets. The observations at Boundary were commenced on the 19th August, 1906, and finished on the 3rd September. During that period on thirteen nights good time determinations were made at Boundary; and seven longitude determinations were obtained with Vancouver and six with Fort Egbert. This probably establised a record,

when we consider the difficulties in the nature of bad wire, etc., that had to be overcome.

As already stated, on the line between Vancouver and Boundary, there were four repeaters, *i.e.*, at each of the four stations there were two repeaters, one for transmitting automatically signals going north, and the other for signals going south. Although these repeaters were all alike, of the Weiny-Phillips type, there was no assurance that the transmission time of a signal going north, was exactly the same as the time of a signal going south. During the exchanges for longitude determination, the signals were sent through the relays as used in ordinary telegraph work. It was impracticable to reverse the repeaters during a night's work, but on the afternoon of September 4th, a test was successfully carried out. The experiment consisted of: (1) exchange of arbitrary signals; (2) repeaters reversed; (3) repeaters reversed, poles reversed; and (4) as usual, same as (1). There was no change made in the adjustment of the points of the repeaters in the various experiments. From these tests the transmission time going from Boundary to Vancouver was $0^s{\cdot}227$ while that from Vancouver to Boundary was $0^s{\cdot}205$, there being only a difference of $0^s{\cdot}022$. It is not, therefore, certain whether this difference is real or apparent. At any rate, it is so small that it is negligible compared with other errors, being only about seven feet at the Yukon boundary. The mean-time required for a signal to go from Boundary to Vancouver, a distance of two thousand miles, was $0^s{\cdot}216$; or a signal travelled at a rate of nine thousand and ninety-one miles per second. After this experiment was completed the different observers packed up their instruments and returned home.

The computations of the observations for longitude were completed early last spring; and by combining the two determinations referred to above, the longitude of the pier at Boundary was found to be $9^h\ 24^m\ 0^s{\cdot}027$, or it is 17·62 feet west of the 141st meridian. In order to lay down the boundary it was necessary to run a line due north and south over a point 17·62 east of the pier. With that end in view, two observers, Mr. G. Clyde Bald-

win, of Washington, and the writer left Ottawa last March (1907), and proceeded direct to Boundary. It was necessary to go into the Yukon over the snow, and the stage drive of 350 miles from White Horse to Dawson was very much enjoyed. The Dominion Government at considerable expense have built and keep in repair a first-class trail. Well equipped road-houses have been placed at distances of about twenty-five miles, and the traveller is supplied with every convenience possible, The journey from Dawson to Boundary was hardly as enjoyable ; the trail runs along the centre of the river and drifts full of snow with every storm. We left Dawson on the 13th April and reached Boundary on the 20th. The snow was very soft and in places we were obliged to " mush " through six to eighteen inches of water and soft snow. Our small load of less than a ton of supplies and instruments was often more than our horses could operate ; and we were obliged on several occasions to dig out the sleigh. However, none the worse for our experience, we reached Boundary, and found the Observatory just as it was left the preceding September. The astronomical transit was mounted on the pier and adjusted in the meridian. An azimuth mark was then approximately placed in the meridian of the telescope, on the top of the hill to the south of the Yukon river, and at a distance of about one and a quarter miles. The snow was over four feet deep all over the hill, and as the elevation is about eighteen hundred feet above the river, considerable difficulty was experienced in the daily climb to clean and light the lantern which gave the light for the azimuth mark.

The micrometric method of azimuth determination was employed in finding the direction of the mark ; in all twenty-four determinations were made, twelve by Mr. Baldwin and twelve by the writer. The mean of all was taken as the final azimuth. The required offsets at the Observatory and at the mark were then made, and the first section of the Yukon-Alaska boundary line was laid down. This line was continued by the surveyors through the summer, and at the present time about one hundred and seventy-five miles have been delimited.

It was stated early in this paper that the different transit telescopes were all fitted with Repsold Micrometers; the main advantage of one of these self-registering devices is that the observer has no personal equation. Personal equation, or the differences between the times at which two observers see the same thing, has always been the weak point of longitude work. An observer's personal equation depends upon his temperament, on his physical condition and on his experience. An experienced observer will have a more constant personal equation than will a beginner. In the spring of 1905 Mr. R. M. Stewart and the writer made a series of determinations of personal equation; the value of which was found to be $0^s{\cdot}097 \pm 0^s{\cdot}007$. In November, 1905, another determination was made when the value was found to have changed to $0^s{\cdot}325 \pm 0^s{\cdot}007$. Since that time a number of determinations of the personal equation of the same two observers has been made and it has remained fairly constant at a value of about $0^s{\cdot}35$. In all these observations Mr. Stewart used an instrument equipped with a glass reticule, while the writer used the transit micrometer. During the fall of 1906 Mr. Stewart made an elaborate series of time observations. He used Cooke II, fitted with a Repsold Micrometer, and also Cooke I, which has a glass reticule. Several nights' work shows a difference of $0^s{\cdot}35$ in his clock corrections, as found with the different instruments. The clock used has practically no rate, and his observations show conclusively that there is no personal equation with the Repsold Micrometer. Other tests have also been carried on at the Dominion Observatory, and they have all proved that the introduction of the transit micrometer has eliminated personal equation. With that uncertain quantity eliminated our longitude determinations are much more reliable, and also can be made with far less expense.

Theory of Transit Micrometer.—The transit micrometer is a form of registering micrometer placed with its movable line in the focal plane of an astronomic transit, and at right angles to the direction of the motion of the image of a star which is being observed as it crosses the meridian. Certain contact points on

the micrometer head serve to make or break an electric current, as they pass a fixed contact spring, and they record upon a chronograph the instant at which the micrometer head, and therefore, the moving micrometer line, reached each of the points corresponding to the contact point. The movement necessary to make the micrometer wire follow a star image is given to the micrometer head by the hand. The record made upon the chronograph is similar to that which would appear there, if a series of fixed lines were in the focal plane of the telescope, and the observer recorded the instant of transit of a star image across each line, as seen by him, by operating an electric key in the chronograph circuit. The computation is made exactly as if the chronograph record had been produced by the use of fixed lines and a key.

The mental process is evidently different in the two cases. In the first case he attempts to observe and record the particular instant of the transit of a star image across a fixed line. The result, as recorded upon a chronograph sheet, depends upon the rapidity of reception and action of the observer. In the other case the time element does not enter directly in the mental process of the observer. He is not trying to note the particular instant at which any event occurs; he is intent simply upon keeping a star image bisected by a movable line which is under his control. In general he sees the star image slightly ahead of or slightly behind the moving line and determines to make the line move more slowly or more rapidly so as to improve the bisection. After an interval which depends upon his rapidity of action the bisection is improved, perhaps made perfect. He soon observes that the bisection is again imperfect and makes an attempt to improve it. This cycle of events, the noting that the bisection is imperfect, deciding to correct it, attempting to correct it, and again observing that it is imperfect, is repeated at a rate which is dependent upon the rapidity of perception and of action of the observer and upon his temperament. His personal equation of the kind which affects the key method of observation is now effective in determining the amplitude and period of the oscillation

of the moving line forward and backward across the star image, but not in fixing the average error of the position of the moving line. The latter is fixed mainly by a personal equation of the same form as if a series of bisections of a fixed star image were being made. The observer may be subject to a personal equation in estimating the position of the image which leads him to habitually place the line slightly to the right or to the left of the image. Such a personal equation in estimating the position of a stationary or slowly moving image has a much smaller effect upon the result of an observation of time with a transit micrometer, than the personal equation in observing the instant of transit has upon the result of an observation for time with the electric key. This is the theory of the transit micrometer. The proof of the correctness of the theory lies in the results which have been secured with a transit micrometer by various observers, some proof of which has already been given in this paper.

While the accidental errors have been reduced by the use of a transit micrometer, yet the principal claim and in all cases the important claim is that it really, if not quite, eliminates from the results the effects of all personal equation on the part of the observer, and hence the effects of variation of the personal equation which would otherwise be present.

It is the hope of the writer that this short paper will give the readers some idea of our great Yukon territory, and a knowledge of our present methods of longitude and azimuth determinations.

ROYAL ASTRONOMICAL SOCIETY OF CANADA,
TREASURER'S REPORT FOR 1907.

1907	Receipts, 1907.		
Jan. 1	Cash in Bank		1135.40
	Interest from Bank	6.60	
	Advertisements in Journal	175.00	
	Sale of Journal	2.48	
	Fees from Members	396.10	
	Governors University of Toronto (50 subscriptions to *Journal*)	100.00	
	City Grant	100.00	
	Ontario Government Grant	600.00	
	Dominion Government Grant	1000.00	
	Total Income		2380.18
			3515.58
	Expenditures 1907.		
	Interest and Exchange	2.10	
	Floral Emblem	2.50	
	Repairs to Telescope	3.00	
	Petty Cash	12.59	
	Postage and Express	28.55	
	Library Fixtures	23.30	
	Gold Medal	25.25	
	Commission on Advertisements	68.85	
	Public Meetings	96.15	
	Rent	100.00	
	Stationery	84.72	
	Assistant Librarian	167.50	
	Books and Periodicals	162.81	
	Postage and Delivery { *Journal* and *Handbook* }	150.33	
	Printing and Engraving *Handbook*	325.75	
	" " " 6 Nos. *Journal*	1173.52	
	Total Expenditures		2426.92
	Reserve Fund in Bank		150.00
	Cash in Bank		938.66
			$3515.58

GEORGE RIDOUT,
Treasurer.

Examined and found correct,
(Signed) JAS. G. BOYCE,
WM. BAIN,
Toronto, April 1, 1908.

MEETINGS OF THE SOCIETY.

AT TORONTO.

February 11.—Observations of Jupiter and Venus were discussed by several of the members. Mr. A. R. Hassard exhibited an eight-inch glass which he has been figuring for a reflecting telescope. The paper for the evening was by Mr. A. F. Miller on "Stellar Motions." This was a continuation of the series of papers dealing with this subject which Mr. Miller has been giving the Society, on this occasion special reference being made to the motion involved in variable stars.

February 25.—The following were elected members of the Society:

Robert Cuthbert, Toronto,

George W. Rudlen, B.A., Sault Ste. Marie.

Mr. R. S. Muir made inquiries regarding the theories of sun-spots and gravitation contained in Kedzie's work on that subject. Mr. Muir explained the theories and the subject was discussed by Messrs. Collins, Tyson and Miller. The latter considered Kedzie's theory of gravity a very rational one, but his views on sun-spots were not so acceptable.

Mr. A. R. Hassard reported observing Jupiter with a four-inch refractor the previous evening when three satellites were visible but the fourth being in transit across the disc could not be seen. Mr. Miller stated that with such a telescope it is often possible to see a satellite on the disc when near the limb.

Mr. J. R. Collins drew attention to the request made by Mr. Phillips of the British Astronomical Association that observers note especially the locality on the surface of Jupiter where the Red Spot was seen some years ago.

The address was by Professor A. T. DeLury, and dealt with the corrections necessary to be applied to astronomical observations on account of atmospheric refraction. The reason for such corrections was explained and a brief account was given of the method of obtaining the formulæ. An illustration of the use of Bessel's tables, those in general use, was also given.

Mr. A. F. Miller asked to what extent Newton carried the

theory of refraction. Professor DeLury replied that the theory was very young at that time, but that Newton's suggestions were doubtless acted on by others.

Professor A. Kirschmann asked whether the formulæ given were for all latitudes, and was informed that they were, but that the question of distance from the centre of the earth would have to be considered.

March 10.—The following was elected a member of the Society :

James G. Workman, B.A., Wingham, Ont.

A Harvard College Observatory *Bulletin* was read stating that Melotte, at Greenwich had discovered a planet or satellite. The President, Mr. W. B. Musson, mentioned the comets expected this year, and stated that Encke's Comet had been photographed in Heidelberg in January. The ephemeris of Halley's Comet was also given. Mr. A. Elvins suggested that in view of the fact that Halley's Comet is in the region of the heavens not far from that containing the satellite referred to in the Harvard *Bulletin*, it was not impossible that what had been taken for a satellite might prove to be a comet. Mr. Musson stated that Daniel's Comet is now visible early in the morning, and is of magnitude about 8½.

The paper for the evening was by Mr. John Phillips on "A Popular Exposition of Darwin's Earth-Moon Theory." Saturn is 4600 times as heavy as Titan, the largest satellite in the solar system, while the Earth is but 80 times as heavy as the Moon. Our satellite, however, is the only one Darwin accounts for in detail. Tracing her past history he finds her approaching the earth and gaining in orbital velocity, the earth at the same time gaining in speed of rotation. Continuing farther back he finds the Moon just grazing the earth's surface and revolving about her in 2 h. 24 m., the earth rotating in the same period. Darwin remarks "Is it then a mere *coincidence* that the shortest period of revolution with which a spheroid of the same mean density as the earth could subsist in the ellipsoidal form is 2 h. 24 m.; whilst if Kepler's Law were to hold true, and if the Moon were

to revolve round the earth in the same period, the surfaces of the two bodies would just graze one another?"

In this condition the system is not stable, and the Moon starts off on her long journey. The Moon receded, the day and the month both increased in length, and this must go on until the day and the month will each be equal to 55 of our present days, at which time the Moon will be some 140,000 miles further out than at present.

March 24.—Mr. J. R. Collins mentioned that the new satellite announced from Greenwich had been observed by Professor Campbell, at the Lick Observatory, on the 8th instant. Its magnitude was about 15. Observation shows that the object is drifting with Jupiter and is probably attached to that planet.

The President reported that Dr. Lewis Swift, of Marathon, N. Y., famous for his discoveries of comets, had celebrated his twenty-first birthday on February 29 and thus completed his eighty-eighth year. He had written to Dr. Swift, offering to him the Society's congratulations.

The address of the evening was by Professor A. T. DeLury on "Corrections to be applied to Observations,—Parallax." In it the speaker explained the meaning of the term and the necessity of the correction. Formulæ were developed, and the method of determining the Sun's parallax by means of a transit of Venus was fully explained. E. A.D.

AT OTTAWA.

February 13.—The President, Dr. W. F. King, read his paper on "Astronomical Cycles." He began by explaining the apparent motions caused by (1). The rotation of the earth on its axis. (2). Its annual revolution around the Sun. (3). The revolution of the Moon about the earth.

These motions were illustrated by the use of a celestial globe. The stars, owing to their enormous distances, appear relatively fixed, as the apparent displacement of the nearest fixed star *α Centauri* owing to the annual motion is less than a second of arc. The smallness of this angle was graphically shown by examples. The first cycle touched on was the precession of the

equinoxes, in which the point of intersection of ecliptic and equator moves backward along the ecliptic about 50″ a year, making a complete cycle in nearly 26,000 years. After showing that no connection could reasonably be found between this period and any terrestrial events, Dr. King went on to consider the motion of the Moon.

The inclination of the orbit of the Moon to the ecliptic is about 5° 08′, the points of intersection of the two planes being called nodes. Like the equinoxes these nodes retrograde on the ecliptic, but much more rapidly, making a complete revolution in about 18·6 years. After distinguishing between sidereal, nodical, anomalistic and synodical revolutions of the Moon, the question of eclipses of the Sun and Moon was discussed.

The Saros or Eclipse period of 18 years 10 or 11 days, which is caused by the coincidence of 223 lunations of 29·53 days and 19 synodical revolutions of the node of 346·62 days, after which Sun, Moon and node will occupy approximately the same positions, and eclipses will recur, was next explained. It was also shown that at the end of this period the Moon is also nearly at the same distance from the earth and consequently not only will eclipses recur but their character will be similar.

Some further considerations relative to the frequency of eclipses of Sun and Moon were given and it was shown that there may be only two eclipses, both of the Sun, or at most seven, of which 4 or 5 are of the Sun.

The lecture, which was illustrated with diagrams and lantern slides, was listened to with much interest and pleasure.

Three questions had been sent for the Question Box.

1. Why at the solstices does not the day lengthen or shorten equally at sunrise and sunset?

2. Does the above phenomenon occur similarly in the southern hemisphere?

3. In determination of stellar parallax the measurements are made using as a base line the earth's distance from the Sun. Why is no account taken of the Sun's motion through space which is of the same order or magnitude?

Nos. 1 and 2 of these questions were answered by Mr. R. M. Stewart, and No. 3 by Dr. Klotz.

February 27.—At this meeting Dr. Klotz presented a paper on "Earthquakes and the Interior of the Earth." It appears in full in another part of this issue.

March 12.—Dr. King gave a paper on "Time." The paper began by a historical résumé of the ancient methods of dividing the day into 12 hours for the day part and into either watches or hours for the night part. No attempt was made to take account of the varying length of the day and the hours were consequently not of uniform length. The Greeks, however, distinguished between these "temporary" hours and the twenty-fourth part of a day which they called an equinoctial hour. The lecturer described the ancient methods of measuring time, the chief of which was the clepsydra or water-clock, of which the hour-glass is one form, and referred to Alfred the Great's method by candles. The sundial was introduced about 340 B.C. by Berosus. A slide of this dial was shown. It consisted of a hemisphere with a bead at the centre. The true sundial was invented by the Greeks. The first clocks came into use in the 14th century. A balance was first used, but Huyghens improved on it by the substitution of the pendulum.

The different forms of clock and watch escapement were then described and illustrated.

Outside influences such as temperature and pressure affect the rate, and Dr. King described the principal means adopted for compensating both pendulum and balance wheels against the effects of changes of temperature.

The methods for compensating for change of pressure and consequent change of density of the air were then described, the most effectual being to enclose the whole clock in an air-tight case from which the air is partially exhausted.

The lecturer then proceeded to speak more particularly of Time itself. The measure of time is derived from the rotation of the earth on its axis, the interval between successive passages of the meridian of a place over a certain point on the celestial

sphere, the First Point of Aries, is called a sidereal day. Sidereal time gains on mean time consequently 3 mins. 56·5 secs. in a day.

Dr. King then explained the meaning of apparent solar time, mean solar time, and the equation of time. The reason for beginning of the astronomical day at mean noon and the civil day at mean midnight was discussed. The disadvantages in the use of local mean time and the improvement effected by the introduction of Standard Time, which was fully explained, was described. The lecture concluded by a statement of the chief places where Standard Time was determined and the means by which it was distributed through the country.

For the Question Box there were the following questions*:

1. What astronomical foundation if any is there for the belief that the character of the weather may be foretold by the position of the horns of the Moon's crescent?

2. What is meant by the opposition of a planet and why are some oppositions of Mars said to be more favorable for observation than others?

These questions were fully and clearly answered by Messrs. D. B. Nugent and W. E. Harper, and some further interesting diacussion of the supposed influence of the Moon on mundane affairs took place.

The attendance was large, and after the meeting an hour or more was pleasantly spent in observation with the telescope.

March 28.—Mr. F. A. McDiarmid read a paper on "Azimuth."

The azimuth of a point or line on the earth's surface is the arc of the horizon intercepted between the vertical circle of the point or line and some fixed reference point or line. Astronomers measure azimuth from the south through the west, while surveyors often reckon from the north through the east. The principal requirements for the accurate determination of azimuth are the correct sidereal time and the latitude of the station. In primary work the time must be determined by one observation. Latitude may be found by any of the ordinary methods.

* It is hoped to publish answers to these and similar questions in the JOURNAL. —Editor.

Mr. McDiarmid then described—illustrated by slides—the different kinds of azimuth marks employed, as also the eye-pieces generally used. Some reference was also made to the dangers of systematic error due to lateral refraction or other causes.

The general formula used was then derived and also that employed when the star was observed at elongation, which is the most favorable position for observation. From a discussion of the effects of errors in time, latitude, and declination on the resultant azimuth, the conclusion was drawn that we must depend for azimuth work on close circumpolars. The corrections for curvature, for level error and for diurnal aberration were then derived and discussed. A short description and comparison of the different methods of determining azimuth showed that the micrometric was most accurate. Mr. McDiarmid then discussed the best method of arranging the observations, and deduced from the results of a number of observations that for accurate values it is preferable to increase the number of nights rather than the number of obervations on one night.

Since the last issue the following have been elected to membership in the Society :

F. W. O. Werry, B.A., Saranac Lake, N.Y.,

Ferdinand Ellerman, Carnegie Solar Observatory, Pasadena, Cal.

J. S. P.

AT PETERBOROUGH.

February 5.—A good audience gathered to hear an address from Dr. W. F. King, the Society's Honorary President. The local president Rev. Dr. Marsh introduced Dr. King, after which Alderman Elliott, on behalf of the city extended a hearty welcome to him and expressed the pleasure they had in his visit.

After thanking the audience and the city for their kind welcome and for the entertainment he had enjoyed during the day in visiting the large manufacturing establishments, Dr. King spoke on the Dominion Observatory at Ottawa and on the progress being made in surveying and geodetic measurements. He stated that the Ottawa observatory was purely for astronomical, not meteorological, purposes. The principal instruments were

described in detail. The large telescope has an object glass 15 inches in diameter, and with the powerful spectroscope a better knowledge will be obtained of the steller systems. The use of the tele-photo lens for photographing the Sun was also explained, as was also the meridian circle by which the right ascension and declination of a star are obtained at a single observation.

Dr. King described various other instruments used, and referred to the library, photographic department and the distribution of time to the city of Ottawa. Speaking of surveys under way, he dealt with the Alaska boundary and the Alaska coast boundary. He fully described the difficulty experienced in the mountainous regions by the surveyors, which makes progress slow. On the southern boundary, work is at present confined to the British Columbia district, but it will be continued eastward to the Lake of the Woods. The survey of the boundary east of the St. Lawrence is also proceeding. The address concluded with a clear account of the methods used to confirm original surveys and to obtain correct maps of the country.

March 9.—Since the last meeting Mr. S. W. Lowry resigned as secretary and Miss Estelle Foy was elected in his place.

Mr. H. O. Fisk gave an address on "Echoes from the Observatory at Ottawa," which institution he recently visited. The handsome building and its fine location were referred to, and an interesting account was given of the large telescope, the spectroscope, the elaborate time-installation, and other portions of the excellent equipment. Another object of interest was a relief map of the Pacific coast, made to exact scale. This was secured chiefly through the camera, which in surveying is now classed almost on an equality with the transit.

Mr. Herbert Collier followed with a paper on "An Hour with the Moon." If a telescope is not available for the study of the Moon, much can be done with an opera glass. By crayon diagrams the outline of the dark surfaces visible to the naked eye were drawn; these are supposed to be dry ocean beds. Many mountain ranges exist on the Moon, some reaching a length of 450 miles and altitudes of 15,000 feet. Observation of the sur-

face of the Moon shows that it has been disturbed by volcanic action. Craters of volcanoes can be seen at various places, some of the gaping mouths being more than 100 miles across, and indicating how great the forces that in years gone by have been in action on our satellite. The magnitude of these openings can scarcely be comprehended, since on the earth the volcano mouths seldom exceed two miles in diameter.

March 16.—On this evening Rev. Dr. Marsh, assisted by Mr. H. B. Collier, lectured in Napanee on "A Night in the Skies." The meeting was held in the auditorium of the Western Methodist Church, and was very largely attended. Much interest is shown in the study of astronomy in Napanee.

April 2.—The following was elected a member of the Society:

Charles M. Stratton, B.A., B.Sc., M.D., M.R.C.P. & S., Napanee, Ont.

The evening was taken up with a discussion of various questions which had been proposed, as follows:

(1.) Why do some stars in the north never set, while those overhead and in the southern portion of the heavens do?

(2.) What are the Northern Lights, what causes them and why are they not visible every clear night?

(3.) Explain the term *declination.*

(4.) What are shooting stars and meteors?

(5.) Do meteors fall on the lighted portion of the earth as well as on that in the dark?

(6.) Why do stars twinkle?

(7.) Explain the meaning of *hour circles.*

(8.) Is there any connection between comets and meteors?

(9.) How can an observer know when a transit instrument is out of the meridian, and how is it corrected?

(10.) When did the Sun cross the equator?

The above questions led to a general discussion which proved very interesting and helpful. Mr. H. O. Fisk brought to the meeting a fine Gurley field transit to enable a practical demonstration in answering question 9. E. F.

NOTES FROM THE DOMINION OBSERVATORY.

Astrophysics.—Although the observing weather since the last issue of these notes has been very poor, only about six wholly clear nights during December and January, radial velocity observations are making satisfactory progress, and considering the assistance available in the work the measurement and reduction of the plates are being kept fairly well up to date.

Work on the spectroscopic binary *ι Orionis*, which has been twice referred to in these notes, has at last been completed. Observations at a critical part of the velocity curve, where it is rapidly changing in form, had been awaited for more than a year, but at the the recurrence of every period, 29·136 days, cloudy weather always prevented their being obtained. The final necessary observations were secured at the end of January. Owing to the very diffuse and asymmetric character of the lines of the star's spectrum, to the high eccentricity of the orbit, and to a probable secondary disturbance, a large number, 107, plates were measured and used in obtaining the elements.

The final values of the principal elements which best satisfy the observations are as follows:

Period	$U = 29{\cdot}136$ days.
Eccentricity	$e = 0{\cdot}75$
Longitude of the apse	$\omega = 110^{\circ}$
Projected length of semi-major axis	$a \sin i = 29{,}680{,}000$ km.
Velocity of system	$V = +\ 20{\cdot}7$ km.

A paper on the orbit of this star by J. S. Plaskett and W. E. Harper will shortly appear.

The spectroscopic binary *ψ Orionis*, of which the elements have also been determined, offers in respect to the difficulty of obtaining them, a curious contrast to the above star. The former was under observation for fifteen months and 107 plates were measured, *ψ Orionis* were observed for four months and satisfactory elements obtained from 37 plates. The quality of its spectrum for measurement is not greatly superior to that of *ι Orionis*, the lines being very broad and diffuse, but the eccen-

tricity of the orbit is small, the velocity curve being consequently more regular in form, and the observations happened to group themselves more favorably. This star also is somewhat peculiar in its short period, 2·5259 days, and its large range of velocity from +151 km. to −144 km. per sec. The values of the principal elements are as follows:

Period	$U = 2{\cdot}5259$ days
Eccentricity	$e = 0{\cdot}063$
Longitude of the Apse	$\omega = 186°$
Projected length of semi-major axis,	$a \sin i = 5{\cdot}103{,}000$ km.

A full account of this star will also be shortly published.

Mr. Harper has recently discovered that the velocity of δ *Herculis* in the line of sight is variable through a fairly wide range, and this star has consequently been added to our observing list of spectroscopic binaries.

The Hartmann Spectro-Comparator which was ordered from Zeiss more than a year ago has recently been received and seems a very workmanlike and complete instrument. Owing to some misunderstanding of the specifications, the occular prism which serves to unite the images from the two spectra had its silvered strips of the wrong dimensions. While waiting for a new prism the present one was taken apart and the silver strips ruled to suitable dimensions allowing measurement to proceed at once. So far as solar type spectra and those of closely allied types are concerned, the machine fulfils all expectations and will evidently give much superior measurements, but at the same time it is also evident that in spectra of the early hydrogen or "between" type, especially if the lines are diffuse, more accurate measurements may be obtained in the usual way. However, as it is only in spectra rich in lines that any saving of time is effected by the use of the Spectro-Comparator, this latter consideration has little weight in estimating the value of the machine for its particular purpose.

I regret to state that the hopes expressed in the last notes of the early completion of the cœlostat house, have not been realized.

Early frosts prevented the cement work from being finished and the mechanism is not yet erected, although in place ready to go up as soon as the opening into the basement of the observatory is completed. This will doubtless soon be done and actual work with the instrument started.

Dr. R. E. De Lury is just completing measures of the wave-lengths of the principal lines in the Spark spectrum of an alloy of iron and vanadium. This alloy is used for comparison purposes in radial velocity work and the wave-lengths of some of the blended lines are uncertain; besides, it seemed preferable to have all wave-lengths determined from one spectrum of the alloy rather than by combining measures from separate spectra of iron and vanadium. The 10 foot focus grating concave was used in producing the spectra. J. S. P.

Meridian Work.—The new Meridian Circle, which arrived about the end of last October, was mounted in the early part of the winter, as soon as some necessary alterations had been made in the piers. The observations made with it have not been very numerous, and were obtained under considerable difficulties, owing to the fact that the Transit House is not yet altogether completed. It was found that the vertical circles had been slightly damaged in shipment, and they were accordingly returned to the makers to be re-turned and re-graduated. Later it developed that the piers on which the instrument was mounted were unstable, owing to the action of the frost; this will unfortunately necessitate their complete reconstruction.

It is proposed to erect piers for azimuth marks north and south of the Meridian Circle. The primary marks will be fixed underground for stability, while on the piers will be movable marks, which can be set vertically over the underground ones by a process similar to that used at the Royal Observatory, Cape of Good Hope. This, it is hoped, will furnish marks whose absolute stability can be relied on for considerable intervals, if not permanently. The collimating lenses for these marks, situated within the building, will also be movable, for adjustment over similar marks.

An observing couch has been designed, and the order has been placed for its construction. It will run on the same rails as the reversing carriage, and will comprise mechanism for quick setting in any desired position, combined with a slow motion for the final adjustment.

Work on the opening mechanism for the roof shutters, and alterations in the vertical wall shutters, is now in progress, and it is hoped to have the reconstruction of the piers pushed to completion as soon as possible. It is likely, however, that it will be some months before the instrument can be got into actual service.

R. M. S.

The Seismograph—Bosch photographic. Periods 5ˢ·7 and 6·0. Magnification 120.—Microseisms or earth tremors, the nature of which is not yet definitely determined, were not particularly well-marked during March. They were pretty strong on the 6th and 25th, giving a maximum amplitude of 1 mm. Generally the N–S component (E–W pendulum) is somewhat the greater. While the average period of these seisms is between 5 and 6 seconds, there are times, not often, when the oscillations will become very much more rapid, and continue so for some hours, being from 15 to 20 per minute or a period of 4 to 3 seconds. The reason for this marked change has not yet become apparent. On March 25 a small earthquake was recorded just after noon. Due to the presence of earth tremors on that day, as above noted, the first preliminary tremors of the quake are marked. The following are the data :

	N–S Component	E–W Component
	h m s	h m s
1st P.T. began	17 02 00 (?) G.M.T.	17 02 00 (?)
2nd P.T. "	17 07 34	17 07 34
Principal Portion began	17 15 00 (?)	17 13 00
Duration	45	1 15
Max. Amplitude	2 mm. at 2nd P.T.	2 mm. at P.P.

It may be noted that the earth tremors continued after the quake, just as before.

On the following day in the evening, March 26, a very severe earthquake was recorded, that of Chilapa on the Pacific slope of Mexico. On the seismogram of this quake some of the phases

are very well marked, so that the deduced distance of the epicentre was in accord with the actual distance within a hundred kilometres. In fact there were two distinct shocks on that day, of which the following are the data :

	N-S Component	E-W Component
	h m s	h m s
1st P.T. began	23 10 12 G.M.T.	23 10 12
2nd P.T. "	23 15 50 (?)	23 15 50
P.P. "	?	?
Duration	3 00	3 45
Max. Amplitude	21 mm. at $23^h\ 29^m\ 40^s$	42 mm. at $23^h\ 28^m\ 40^s$.
For the other		
1st P.T. began	3 54 12 (Mar. 27) G.M.T.	3 54 12
2nd P.T. "	3 59 45	3 59 44
P.P. "	4 04 40 (?)	4 05 28 (?)
Duration	1 20	2 05
Max. Amplitude	17 mm. at $4^h\ 10^m\ 32^s$	20 mm. at $4^h\ 11^m\ 08^s$.

In both seismograms the beginning of the principal portion is difficult to locate, although the long waves are clearly shown, but the transition from 2nd P.T. to P.P. is not easily recognized. In both quakes the 1st P.T. is beautifully sharp. Small earth tremors were present before the quakes, they are seen between the quakes, and continue thereafter, but become very small.

Up to the time of writing (April 15), earth tremors have been more in evidence during April than in the preceding month. To be especially noted are those of the 3rd and 4th, and those of the 10th, 11th, 12th and 13th, reaching an amplitude of 1·5 mm.

From correspondence it is learned that during March several slight earthquake shocks were felt at Baie St. Paul, on the north shore of the St. Lawrence, about half-way between Quebec and the mouth of the Saguenay. The most distinctly felt shock was in the evening of March 10, and was supposed to come from the southwest.

This (Baie St. Paul) is a well-known seismic area, situate on an igneous extension in the vast Laurentian formation lying to the north of the St. Lawrence, and which is separated from the Cambrian formation on the south shore by the "Great St. Lawrence and Champlain Fault," along which occurred the noted and historical earthquake of 1663. O. K.

ASTRONOMICAL NOTES.

In a paper on "Seismic Radiation," appearing in *Proceedings of the Royal Society of Edinburgh*, 1907–8, 224, Professor C. G. Knott remarks:

"The observed facts of seismic radiation can be co-ordinated on the assumption that throughout all but a comparatively thin crust of the earth the elastic waves of highest speed are transmitted with a speed of 12·23 kilometres per second, and that within this crust, of thickness equal to one-tenth the radius, the speed diminishes from value 12·23 kilometres per second at the inner surface to 6 kilometres per second at the outer surface."

Mr. W. Goodacre contributed a paper on "Gueriké" before a recent meeting of the British Astronomical Association. "The writer's object in referring to this formation was to draw the attention of lunar observers to the detection by Mr. A. Noel Neate of a hitherto-unrecorded linear marking on its floor and close to the western wall. He did not suggest that it was of recent origin, but it was another example of the truth of the statement that any observer, using even a small telescope and persistently studying some selected portion of the lunar surface, would sooner or later detect objects hitherto unrecorded."—*The Observatory*, March, 1908.

We are informed that the Manora Obeservatory in Lussinpiccolo (Austria) will cease to exist within several months. Among the instruments to be sold there is also the 7-inch equatorial which was declared by twelve astronomers who examined it, a *unicum* in perfection and performances. It enabled Herr Brenner to measure the companion of Sirius at a time when it was shown only by the Lick refractor (dist. 3″·74) and star β 79 (dist. 0″·54), to discover 200 new objects on Mars; it showed all satellites of Uranus, Mars, Neptune and the 8 older of Saturn and hunreds of markings on Venus and Mercury.

J. R. C.

SUMMARY REPORT OF THE WEATHER IN CANADA.

FEBRUARY 1908.

TEMPERATURE.—The temperature was very slightly below the average in British Columbia, considerably above it from the Rocky Mountains to the Lake Superior Region, much below the average from the Georgian Bay district and eastward as far as the eastern part of the Province of Quebec and above it in nearly all portions of the Maritime Provinces. In the Western Provinces the positive departures ranged from 8 to 12 degrees and in the Maritime Provinces from 1 to 4 degrees. The negative departures in Ontario ranged from 2 to 6 degrees and in Quebec from 1 to 3 degrees.

For highest and lowest temperatures see the table below.

PRECIPITATION.—The precipitation was much in excess of the average over the greater portion of Canada, in most districts from 50 per cent. to 100 per cent. more than the normal. It was, however, from 20 per cent. to 40 per cent. deficient in Alberta, and there were also deficiencies of about 20 per cent. very locally in British Columbia, Manitoba and the southwestern portion of the Maritime Provinces.

THICKNESS OF ICE.—Thickness of ice as reported from the various stations is as follows :—

Western Provinces.—Edmonton, 26 in.; Battleford, 24 in.; Swift Current, 30 in.; Minnedosa, 30 in.

Ontario.—Port Arthur, 15 in.; White River, 12·5 in.; Southampton, 18 in.; Pt. Stanley, 15 in.; Ottawa, 30 in.; Rockliffe, 42 in.; Arden, 20 in.; Bruce Mines, 25 in.; Strathroy, 20 in.; Port Burwell, 18 in.; Clinton, 20 in.; Gravenhurst, 22 in.; Peterboro', 22 in.; Sutton West, 22 in.

Maritime Provinces.—Chatham, 15 in.; Charlottetown, 11·5 in.; Yarmouth, 6·5 in.; Sydney, 3 in.; Fredericton, 22 in.

DEPTH OF SNOW.—In British Columbia at the close of the month the ground was bare of snow in portions of the lower levels of southern districts, whilst in the north and higher levels there was a deep covering.

Southern Alberta was bare of snow while elsewhere the depth was almost generally about three inches. A depth of from

2 inches in the south to 12 inches in the north was reported from Saskatchewan. Manitoba was covered with snow to a depth of about five inches.

In Ontario the depth increased eastwards from about four inches in the Rainy River District, and northwards from ten inches and over along the shores of the Lower Lakes, to from thirty to forty-six inches in the Georgian Bay, Temiskaming and Ottawa Valley Districts.

The western portion of Quebec was snow-covered to a depth of from 30 to 50 inches, while the Gaspé Peninsula had 24 inches.

In the Maritime Provinces the depth decreased from nearly 20 inches in the north parts until there was only a trace on the ground in Southern New Brunswick and in Nova Scotia.

MARCH 1908.

TEMPERATURE.—The mean temperature for March exceeded the average over the Lower Mainland of British Columbia, Southern Alberta and a large portion of Ontario; elsewhere in Canada the temperature was subnormal.

For highest and lowest temperatures see the accompanying table.

PRECIPITATION.—The precipitation which in all the provinces was part rain and part snow, was below average over the larger portion of the Dominion. The amount recorded, however, near the Coast of British Columbia, was nearly double the normal, and over Northern Alberta, part of Saskatchewan, northwestern Quebec, Prince Edward Island and in Cape Breton the average was exceeded.

DEPTH OF SNOW.—At the close of the month the ground was bare of snow in Southern Alberta, the Peninsula of Ontario, Southern New Brunswick and Nova Scotia, elsewhere in Canada the covering was light except in northern portions of Saskatchewan and Ontario, where the depth of snow on the ground exceeded twenty inches. In Quebec the amount on the ground ranged from ten inches at Montreal to forty-two at Quebec City.

THICKNESS OF ICE.—Thickness of ice is reported as follows:—Battleford, 24 in.; Medicine Hat, 10 in.; Swift Current, 38 in.; Minnedosa, 24 in.; White River, 13·5 in.; Kingston, 12 in.; Rockliffe, 39 in.; Ottawa, 12 in.; Chatham, N.B., 13·5 in.; Sydney, 8 in.; Charlottetown, 8 in.

Temperatures for February and March

Station	February		March	
	Highest	Lowest	Highest	Lowest
Yukon				
Dawson	34	-40	34	-42
British Columbia				
Agassiz	53	20	59	28
Atlin	38	-24	38	-16
Barkerville	40	- 4	40	- 4
Beaver Lake			46	14
Cowichan				
Kamloops	46	- 2	58	5
Nelson	44	- 2		
New Westminster	52	18	54	28
Nicomen	53	15		
Port Simpson	46	20	46	26
Rossland			46	14
Spence's Bridge				
Vancouver	50	17	56	26
Victoria	56	24	55	27
Western Provinces				
Battleford	44	-20	44	-31
Calgary	62	-14	56	-12
Edmonton	53	-22	52	-16
Medicine Hat	52	-16	60	- 7
Minnedosa	44	-21	43	-24
Prince Albert	44	-26	48	-34
Regina	38	-30	42	-17
Swift Current	43	-16	46	-15
Winnipeg	38	-25	41	-23
Ontario				
Agincourt	43	-22	60	1
Alton	40	-32		
Bala				
Bancroft	40	-38	50	-16
Beatrice	40	-35	48	- 5
Bloomfield			50	2
Brantford	44	-21	64	0
Bruce Mines	40	-27	47	-11
Clinton	41	-24	57	- 1
Clontarf	42	-33		
East Toronto			62	6
Gravenhurst	43	-31		
Haliburton	39	-32		
Hamilton				
Huntsville	40	-34		
Judge	41	-46		
Kenora	38	-30		
Kingston	40	-28	45	2
Kinmount	46	-40	48	-21
Lake of Bays				

Station	February		March	
	Highest	Lowest	Highest	Lowest
Ontario (Cont.)				
Lake Talon				
Lakefield			58	- 2
Lucknow			52	- 5
Madoc	38	-31		
Meaford	42	-21	55	0
Midland			58	5
Otonabee				
Ottawa	37	-23	46	- 2
Owen Sound	43	-22	54	- 2
Paris	40	-22	61	- 1
Parry Sound	40	-32	50	- 6
Peterboro'	41	-29		
Port Arthur	39	-17	51	-12
Port Burwell	42	-13		
Port Dover	41	-17	62	5
Port Stanley	44	- 7	56	9
Rockliffe	49	-39	48	-19
Ronville	40	-38		
Sarnia	45	-15	67	15
Southampton	41	-16	53	0
Stony Creek	45	-15	70	15
Stratford	39	-21	56	1
Sutton West	42	-31	52	- 3
Toronto	44	-18	64	8
Uxbridge	42	-21	53	- 6
Wallaceburg	47	-11	63	13
Welland	44	-12	64	12
White River	38	-44	40	-38
Quebec				
Brome			52	-12
Father Point	43	-14	42	- 5
Montreal	40	-21	46	1
Quebec	40	-24	44	- 7
Sherbrooke	41	-31	54	-11
Maritime Provinces				
Charlottetown	48	- 9	46	2
Chatham	51	-28	53	-11
Fredericton	49	-29	54	- 9
Halifax	49	- 7	52	7
Moncton			51	-12
Parrsboro'			55	- 4
Port Hastings				
St. John	50	-13	48	- 1
St. Stephen	50	-27	53	-15
Sussex	54	-23		
Sydney	50	0	48	0
Yarmouth	50	0	52	10